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Mouth size of largemouth bass in relationship to size of forage fishes

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MOUTH SIZE OF LARGEMOUTH BASS IN RELATIONSHIP

TO SIZE OF FORAGE FISHES

by

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INTRODUCTION

Since the turn of the century, investigators in many fields of biology have been concerned with the empirical determination of relationships between body dimensions of many plants and animals. In fisheries research most of the emphasis has been placed on the determination of mathematical equations to express the relationships between body dimensions and weights of many fresh as well as salt water species of fish. To date no comprehensive study of the relationships between body measurements of fresh water fish has been attempted. Furthermore, reliable information concerning the relationships between body dimensions of fish from well managed farm fish ponds is not available.

Since the development of pond management techniques using bluegill bream (*Lepomis macrochirus* Rafinesque) and largemouth bass (*Micropterus salmoides* Lacepede) as the basic components of the fish population, numerous questions concerning the sizes of fish that are available as food for the largemouth bass and other species of pond fish have arisen. For example, in the determination of the number of pounds of small bluegills that are available as food for the bass it is important to know the maximum size of bluegill that a bass of a given length can swallow. The necessity for such information was emphasized by Swingle (1950, p. 28): "Since the 'C' species can eat only sizes that they are able to gulp and swallow, the maximum depth . . . of 'F' species would appear to be the only dimension of importance to the fishes in a population".

In this investigation the relationships of total length to maximum depth of body of certain species of forage fish adapted to farm pond culture are presented. Similar information on the two most commonly used bait minnows is also given. Information on the relationships of mouth width (cleithrum width) to total length of largemouth bass is also presented. The relationships between mouth widths of bass and maximum depths of body of forage fishes were then combined, and the estimated sizes of forage fishes various sizes of largemouth bass can swallow are tabulated.

REVIEW OF LITERATURE

Concepts Pertaining to Relationships of Body Dimensions of Fish

To adequately develop the fundamentals of relationships of body dimensions of animals, it will be necessary to define body form and to briefly review the mathematical equations used to describe these relationships. The present day conception of form, as given by Thompson (1942), is stated in terms of both magnitude and direction. Thus, in speaking of form, one is considering the extension of a body in several directions of space. Thompson also stated that Archimedes taught that in similar figures the surface increases as the square of the dimensions. Taking L as a linear dimension one may express the general equation of Archimedes as follows:

$$S \text{ increases approximately as } L^2$$

where S is surface area. The application of this geometric relation of Archimedes to biological data was apparently first recognized by Spencer (1866, p. 112): ". . . in similarly-shaped bodies, . . . the strengthe vary as the square of the dimensions."

The first modern approach to the expression of the relationship which exists between body dimensions, that is the relationships between length and depth, length and breadth, and depth and breadth of similar animals, was advanced by Spencer (1873, p. 194):

> . . . equality of things and equality of relations. While organic, and more especially animal forms, occasionally exhibit this perfection of likeness out of which the notion of simple equality arises, they more frequently exhibit only that kind of likeness which we call similarity; and which is really compound equality. For the similarity of two creatures of the same species but of different size, is of the same nature as the similarity of two geometrical figures. In any case, any two parts of the one bears the same ratio to one another, as the homologus parts of the other. . . . if we express this relation between two parts in the one, and the corresponding parts in the other, by the formula A is to B as a is to b; if we otherwise write this, A to B = a to b; if, consequently, the fact we prove is that the relation of A to B equals the relation of a to b; then it is manifest that the fundamental conception of similarity is equality of relations.

This conception of similarity of Spencer's might be written as the following equation:

$$\frac{A}{B} = \frac{a}{b}$$

It might be well to pause at this point and consider the implications of Spencer's conceptions of similarity. These may be summarized in three parts: First, he recognized that there was undoubtedly some unique form for each part of the body of a given species as well as a unique form for the species itself; Second, he believed that this form was maintained in practically the same proportions throughout the life of the individual of that species; Third, he advocated the establishment of mathematical expressions to specify this form and the relationships which exist between different size groups within the same species.

Thompson (1942) stated that sometime around 1900 another equation, known as the "compound interest law" or constant differential growth ratio, was proposed to more accurately describe the relationships between body dimensions of plants and animals. The equation employed for this relationship was as follows:

$$Y = bX^k$$

or

$$\log Y = \log b + k \log X .$$

Huxley (1932) and others believed that this "law" was of general application to cases of differential growth rates. Their contentions were based upon evidence gathered from measurements of different body appendages of crustaceans and higher animals as well as data secured from plants. Thompson (1942) stated that he did not find this to be true except under exceptional circumstances and in transient phases. Thompson found many animals following a "simple interest" rather than a "compound interest" law. His contentions were based primarily upon evidence secured from studies of adult forms of insects and crustaceans. He further stated that the "compound interest" rate of growth occurs under special conditions and for brief periods, but it is the exception rather than the rule, whether for a population or in a single organism. In the case of differential growth, the "compound interest" law applies, thus this law describes a natural mode of growth but its range is limited.

Crozier and Hecht (1914) found that in the weakfish, Cynocion regalis, length, width, and depth were closely related to one another and could be expressed by simple mathematical equations.

In addition "tangents" for relations between total length and standard length, head length, body length, tail length, width, and depth were determined. These "tangents" were calculated by using units shown on plots of the data. The tangent of a line was then estimated by dividing the vertical distance between two points on this line by the horizontal distance. Using the terminology of analytical geometry, this would be stated as follows:

$$\frac{Y_2 - Y_1}{X_2 - X_1} = \text{"tangent"} = \text{slope of line.}$$

Later Hecht (1916) gave his findings concerning the relationships of total length to body length, tail length, head length, depth, and width for six more species of salt water fish. The relationships between total length and other body dimensions were expressed by the equation:

$$Y = b + cL$$

where Y equals such body dimensions as depth, width, etc.; c is a constant; L is total length; and b is the origin on the Y axis of coordinates. Since the calculated b's approached (0,0) in all cases the following abbreviated equation was proposed:

$$Y = cL$$

He further stated that the relation of maximum width of body to total length is rather constant ($\pm$ 15 percent), whereas the relation of depth is highly variable ($\pm$ 55 percent) for teleost fishes.

Hecht summarized the findings concerning the relationships between body dimensions of fish up to 1916. The major points, which have not already been discussed, are as follows:

1. The rates of growth of the different selected parts of fish are identical.
2. Comparisons with other data indicate that, in animals having an indeterminate growth, the external form is established early in the post-embryonic life of the individual and is adherred to,

within rather narrow limits, for the rest of its life. In animals with determinate growth, the external form changes continually during the period of growth, and as soon as the form becomes constant, growth ceases.

3. Depth varies from species to species, and seems to be largely responsible for the special form of a species.

Hile (1936) determined the length-depth and length-width relationships of 95 preserved specimens of cisco (*Leucichtys artedi*). From these data Hile concluded that both males and females grew more rapidly in depth and width than in length.

One of the most thorough studies of the relationships between body dimensions was that of Shapiro (1943) on several species of scrombroid fish. In his introduction it was pointed out that organisms generally show a positive acceleration of growth during early development, after which the velocity shows a negative acceleration. Simple growth only deals with increase in general size, while relative growth deals with growth and size in many dimensions in relation to that of another dimension. These relations determine the form of the organism.

In these scrombroid fishes that Shapiro studied, the length-depth relationship was expressed by the linear equation given below:

$$Y = a + bL$$

The values of b ranged from 0.75 for *Vormer setapinnis* to 1.25 for *Trachinotus falcatus*. In *V. setapinnis* the body became more slender with increase in length while in *T. falcatus* it grew more robust with increase in length.

In all species of fish studied by Shapiro the width increased at a proportionally greater rate than the length. He concluded that in these species of scrombriform fishes changes occurred more rapidly along transverse than along vertical axes, and species which are deeper and wider initially become relatively more slender and thinner with age and vice versa. In the species he studied, the body form was more diverse in the young stages and what might be called interspecific regulation in growth tended the adults toward a more uniform and conventional fish form.

Studies of relationships of body parts conducted within the last 15 years have utilized more modern statistical methods in the analyses of the data. Some of the objectives of these recent investigations were as follows: 1, to obtain larger and unbiased samples of fish from the population under investigation; 2, to obtain more accurate individual measurements of the features being considered; 3, to determine the regression equations which best "fit" the relationships of the variables being studied; 4, to apply the most appropriate statistical "tests" to the data to estimate "within" and "between" population variation.

One of the first applications of modern statistical tests to freshwater fisheries data was that by Mottley (1941) in his investigation of the use of scales of rainbow trout (Salmo gairdnerii) to make direct comparisons of growth. His application of analysis of covariance techniques to interpret the results was not only an advancement but also a stimulus to others in the field of fisheries research.

The next outstanding application of modern statistical techniques to the study of relationships of body parts of fishes was by Martin (1949). In this study of relative growth of body parts of some 20 species of fish it was demonstrated by plotting that the following power regression or allometry equation

$$Y = cX^k$$

or

$$\log Y = \log c + k \log X$$

did not fit over the entire range of length for a species. It was shown that there were changes in the slopes of the relative growth lines which were termed growth inflections. Such growth inflections occurred at very early stages of development, at about 30 millimeters of length, and at sexual maturity. Martin chose to use straight lines with sharp breaks at inflection points rather than use curves at these breaking points. These straight line segments of the growth curve were termed stanzas, and each stanza had a different relative growth constant.

In controlled growth experiments with rainbow trout, Martin used analysis of covariance to determine differences in body form as effected by environmental control. Thus he was able to show conclusively that changes in body form were produced by different temperatures. It was also shown that size at growth inflection was more important than slope in the determination of body form. The use of straight lines to represent stanzas of growth permitted the use of conventional analysis of covariance techniques.

It has been demonstrated by a number of other workers that relative growth relationships of various body parts of fish over a large length range may give nearly but not quite linear plots even on logarithmic coordinates. This was emphasized by Godsil (1948) in his study of relationships of body parts of the yellowfin tuna (Neothunnus macropterus) and albacore (Thunnus germo) from various localities in the Pacific. He tried the conventional linear, quadratic, cubic, power and exponential regression equations to fit his various total length-body part relationships. He concluded that none of these equations gave sufficiently accurate fits of the data and used the following equation for his analyses:

$$Y = a + bX + c/X$$

It should be pointed out that the variates fitted to this line by Godsil were measurements from fish which varied from 497 to 1526 millimeters in total length. The differences in regression lines for fish from various localities in the eastern Pacific were then tested by directly comparing the sum of squared deviations from the individual sample regression lines with the sum of squared deviations of all variates in all samples from the "total" regression line. The F values were determined from ratios of the between regression mean squares to the deviations from individual regressions mean squares. It was found that in samples taken from the same area and containing fish of the same size there were significant differences between samples for the total length-body parts relations under consideration.

The statistical heterogeneity which Godsil obtained was attributed to incomplete mixing of the fishes from various spawning areas. As pointed out by Schaefer (1952) the lack of statistical homogeneity was probably due to the great differences in size composition of the several samples and to the approximate nature of the regression equation employed.

Since the analysis of variance tests gave significant differences between local populations, the differences between local and foreign populations were determined by comparison of the foreign regression line with the local total regression line. He stated that these comparisons of deviations from regression in general amplify the analysis of variance tests. While local sample regression lines varied some from the local "total" regression line, foreign sample regression lines varied to an extent many times that of the local variates.

In other studies of the relationships of body parts of yellowfin tunas carried on by Schaefer (1948), Schaefer and Walford (1950) and Schaefer (1952) linear regression was used wherever possible. Schaefer states that the relation between body depth and total length seems to have been well described by linear regression over the entire size range from 451 to 1785 millimeters of total length. Quite often where relationships between length and various body parts gave strongly curvilinear regressions, transformations by the allometeric equation or by other equations were used to give linear or nearly linear relations.

After determining the type of regression to be used for a particular relation between total length and a body part, analysis of covariance was used to test the difference between different groups of tuna. However, Schaefer (1952) concluded that comparisons of body proportion data on tunas from many different regions by regression analyses were beset with many difficulties, but these difficulties seemed not to be critical in this instance where the differences dealt with were of sufficient magnitude so that sensitive methods were not required. This problem would become acute where the differences to be measured were small.

The types of regression equations used by students of relative growth to describe body form were summarized by Marr (1955). The three forms of regression to which the relationships of body parts to body length most commonly conform are the following:

1. Rectilinear regression expressed as

$$Y = a + bX$$

This regression will always form a straight line on arithmetic coordinates.

2. Power regression or allometry equation expressed as

$$Y = cX^k$$

This regression forms a straight line on logarithmic coordinates. Transformation to logarithms yields

$$\log Y = \log c + k \log X$$

3. Exponential regression expressed as

$$Y = pe^{kX}$$

This regression forms a straight line on semi log coordinates. Transformation to logarithms yields

$$\log Y = \log p + k(\log e)X$$

Such straight line regression as may be obtained by these three forms lends itself to conventional methods of characterizing the lines, computing their variance, and comparing them. Marr further states that length is commonly used as a measure of size, but this represents only one dimension and may, therefore, not be the best measure of size. Also various life history stages may involve different growth stanzas and will thus complicate interpretation of the results of statistical tests.

Development of Statistical Concepts Pertinent to Study of Relationships of Body Dimensions

Since this study is concerned only with the application of accepted statistical methods to obtain information from body measurement data, the review of statistical concepts will be brief and limited. In this section will be pointed out the sequence of developments of various statistical concepts, thereby establishing what statistical tools were available for biologists to use during the period covered by the previous discussion.

Apparently astronomers in the early 1800's were the first to employ points on a chart to represent the results of their observations on the position of stars. Although the ancient Greek mathematicians apparently developed the equation of a straight line of the form given below:

$$Y = a + bX$$

to better understand their geometric drawings, it was the astronomer, Herschel, in 1830 who first applied it to observational data (Thompson, 1942). Herschel stated that the results obtained from this straight line in relation to a group of points, which were observations on stars, were more trustworthy than the observations themselves.

Within the 20 years following this first application of a straight line to a group of points to obtain estimates, two more very important mathematical contributions to the study of variation were developed. In 1846 the Belgian mathematician and astronomer, Quentlet, developed his famous "curve of errors" to study the distribution of variations from the mean of the sample data.

In that same year another Belgian, Bravais, presented a method of computing the joint variation of two or more variables. The equation of this covariation of Bravais was of the form:

$$r = \frac{S(xy)}{n\sigma_x \sigma_y}$$

According to Pearson (1896) the fundamental theorem of correlation was first and almost exhaustively discussed by Bravais.

Galton, according to Pearson (1896), introduced an improved notation for correlation of two variables which may be called "Galton's function" or "coefficient of correlation". The results were practically the same as those given by Bravais. However it was Galton who is credited with applying "the law of errors in the position of a point in space" to the problem of correlation in the theory of evolution.

Yule (1897) in his review of the significance of Bravais equation for regression stated that the term "regression" was introduced by Galton while studying the correlation of sons' with their fathers' height.

Davenport (1900) in his review of statistical developments credits Galton with the development of the quantitative theory of individual variation. In 1885 Galton introduced a graphic method of determining probable error from his normal curve. Then in 1888 he presented another graphic method for determining the measure of correlation between two organs. It is believed that his application of these statistical techniques to biological data was largely responsible for the widely stimulated interest in mathematical studies of variation about 1900.

From the 1890's through the early 1930's notable statisticians such as Karl Pearson, R. A. Fisher, F. Yates and others were developing "modern" statistical theory and methods. Incidentally these men were also actively engaged in various fields of biological research. Two major contributions of this period were: first, the development of methods of obtaining unbiased statistics or estimators for population parameters from small samples; and second, the various probability tables and techniques for "tests of significance" and methods of estimating "confidence intervals". Research workers in practically every field are indebted to R. A. Fisher for his efforts to present exact methods of statistical analysis in his eleven editions of "Statistical Methods for Research Workers". The first edition was published in 1925, and since that time the succeeding editions have been revised to include the new techniques that have been developed. It is noteworthy to mention at this point that research workers are indebted to other statisticians, such as Professor G. W. Snedecor, for further digesting and applying the works of Fisher and others to biological data.

From the preceding discussion it is evident that biologists in the late 1800's were responsible for providing the stimulus for mathematicians to develop statistical theories to better account for the variations in small samples of individuals drawn from the same large population. It may be said that these early biologists used the most appropriate mathematical and statistical techniques at their disposal to analyze their data. However, in more recent times many biologists have failed to use modern techniques of analysis and as a result have not obtained the maximum amount of information from their data.

METHOD OF PROCEDURE

The information used in this investigation was obtained by several means over a period of approximately five years. The data for the investigation of the relationships of body measurements of various species of fish were obtained by measuring specimens recovered either by draining or poisoning ponds or lakes. All measurements were made immediately after collecting the fish and in the majority of cases the fish were still alive. The data for the determination of sizes of forage fish a bass can swallow were obtained by laboratory experiments with living specimens. Data for the demonstration of field application of the size relationship of largemouth bass to forage fish were obtained by draining a pond and counting, measuring, and weighing the different species present. These different study techniques will be presented separately.

Body Measurements of Fish

Six species of fish were included in the study of relationships of body measurements. Of this group only the largemouth bass, *Micropterus salmoides* Lacepede, is piscivorous. The other five species are largely insectivorous:

Bluegill, *Lepomis macrochirus* Rafinesque
Redear sunfish, *Lepomis microlophus* Gunther
Green sunfish, *Lepomis cyanellus* Rafinesque
Golden shiner, *Notemigonus crysoleucas* (Mitchill)
Goldfish, *Carassius auratus* (Linnaeus)

Data concerning the areas of the ponds or lakes from which the specimens were collected, the dates when the ponds or lakes were stocked and drained or poisoned, plus the number and size range of the specimens in a sample from a body of water are given in the Results and Discussion section. All ponds except Lay Lake, Jordan Lake, Martin Lake, King's Pond, Long Creek Pond, and Delos Pond were located on the Farm Ponds Project, Alabama Polytechnic Institute Agricultural Experiment Station, Auburn.

Total length and maximum depth were measured on each fish and the mouth width was also measured on all largemouth bass. Measurements were made and recorded to the nearest millimeter.

Total length was obtained by the following procedure. The fish were consistently placed on the measuring board on their right side. The lower jaw was pressed against the end board and gentle pressure was exerted on the body to hold the mouth closed. The caudal fin was flattened and the two lobes straightened but not pressed together as has been advocated by Hile (1948). With a fish in this position the total length measurement was made from the tip of the lower jaw to the tip of the caudal fin (Figure 1).

Maximum depth of body was measured by placing the fish on its side with its belly against the end board (Figure 2). While exerting gentle pressure, but not sufficient to compress the belly, the measurement was taken just anterior to the insertion of the dorsal fin.

The measurement of the mouth width (cleithrum width) was made by placing the bass belly-down on the measuring board. The operculum of one side was placed against the end board and, while holding the

Figure 1. Method used to obtain measurements of total lengths of largemouth bass and forage fishes included in this study.

Figure 2. Method used to obtain measurements of maximum depth of body of forage fishes.

opercular flap closed on the other side, the measurement was read at the posterior margin of the preoperculum (Figure 3).

In determining the simple linear relationship between total length and mouth width, the sums of squares and cross products for each pond population of largemouth bass were computed using first, the actual values of measurement data, and second, the logarithmic values of measurement data. The simple linear regression equation used for the actual values of data was as follows:

$$M = a + bL,$$

and for the logarithmic values of data it was

$$\log M = \log a + b \log L,$$

where M is the mouth width and L is the total length of bass.

In the studies conducted by Godsil (1948) and Martin (1949) it was shown that the regression of different body parts on length of various fishes did not give linear relations, even with transformations to logarithms. However, Schaefer (1948, 1952) stated that regression of depth on length for yellowfin tunas followed a linear relation over the entire range of lengths included in his data. It was pointed out by Marr (1955) that the use of straight line relations made for easier use of conventional statistical tests. In this present investigation it was desired to use linear equations to describe relations between total length and mouth width and total length and maximum depth of body so that reliable estimates of variance could be obtained. Also it was felt that linear regression would permit application of more conventional statistical tests to the relations between populations of a given species.

It could not be determined from plotting of data whether or not a

Figure 3. Method used to obtain "mouth width" measurements of largemouth bass.

rectilinear or allometry equation would best represent the relation of total length to mouth width for largemouth bass. Plotting these data on arithmetic coordinates gave strongly curvilinear relations, while plots on logarithmic coordinates gave moderately curvilinear relations, thus it was realized that no single regression line could be fitted over the entire range of total length for these bass. It was noted in large plots of these individual data that breaks or growth inflections, such as described by Martin (1948), occurred at approximately 100 millimeter intervals of total length. However, without computing, it was impossible to determine whether actual or logarithmic values of the data would give the best estimating equations for these 100 millimeter interval groups.

Plotting of the total length - maximum depth of body data for forage fishes was done on arithmetic and logarithmic coordinates. In each case practically linear relations were obtained, but again it was impossible to determine if actual or logarithmic values of data would give the best estimating equations.

Since the prediction equations for largemouth bass and forage fishes had to be combined to permit the estimation of sizes of forage fishes a largemouth bass can swallow, the selection of the appropriate values of the data to use in computing had to be based upon these final estimates. However, since all calculations had to be made to obtain these estimates, the results are included in this discussion so that the differences obtained from each set of values may be compared. In the final application, the estimating equations determined from actual values of data were used since their estimates were as accurate as those obtained from logarithmic values and the work involved in computing them was much less.

An effort was made, however, to determine the type of equation which would be most descriptive of the relationship of total length to mouth width of bass for the range of total length from 31 to 595 millimeters. The two following relations were computed using the average mouth width for each 10 millimeter interval of total length of bass:

$$M = a + bL + cL^2$$

and

$$M = a + bL + c/L$$

Sizes of Forage Fishes a Largemouth Bass Can Swallow

The second objective of this investigation was to determine the total length of various forage fishes which a largemouth bass of a given total length can swallow. To accomplish this, it was first necessary to make measurements of the bony structures, located around the esophagus, that would limit the size of fish which a bass can swallow. To verify the results of these measurements laboratory feeding tests, using living specimens of largemouth bass and forage fish, were conducted.

The skeletal structures making up the pectoral girdle of a largemouth bass were originally described by Shufeldt (1883). Since this first description, the nomenclature of the various bones forming this girdle has changed, and the names used in this study will conform with those proposed by Adams and Eddy (1949).

Measurement of the maximum inside horizontal distance or width of the pectoral girdle in the region between the cleithrum bones was made on individual largemouth bass in the following manner. The mouth of the bass was opened and a dull pointed divider in the closed position was inserted into the mouth. The tips of this closed divider were then pushed into the opening of the esophagus for a depth of one-fourth to one-half of an inch, depending upon the size of the bass. While in this position the tips of the divider were forced apart until the pectoral girdle was stretched to its "maximum" width. This "maximum" width was estimated by the amount of pressure being applied to spread the tips of the divider, and by noting the bulging of the girdle. When the posterior margin of the cleithrum bones became noticeably distended from its usually flattened position, it was assumed that the maximum spread of the girdle had been obtained. The technique employed is shown in Figure 4. Locking the divider securely at this angle, the tips were slipped out of the esophagus and removed from the mouth and the distance between the tips was measured to the nearest millimeter (Figure 5).

External measurements of the distance between the posterior margins of the preopercula were then made on the same largemouth bass in the same manner as previously described (see Figure 3). It was found that the width of the bass between the posterior margins of the preopercula, with the opercular flaps closed was, for all practical purposes, the same as the inside measurements between the cleithrum bones (Table 1). Thus the exterior preopercula width measurements are termed mouth widths in this study.

A series of laboratory experiments was conducted during the summer of 1954 to determine the maximum size of various forage fishes largemouth bass can swallow. In these tests, 29 largemouth bass ranging in size from

Figure 4. Method used to determine width between cleithrum bones with divider.

Figure 5. Measuring distance between points of dividers which were set at "maximum" cleithrum width for the bass shown.

Table 1. Inside measurements between cleithrum bones with accompanying external measurements of mouth widths of 20 largemouth bass.

Total length mm.	Cleithrum width mm.	Mouth width mm.
158	15.5	16.0
180	20.0	20.0
195	19.0	19.0
197	20.5	20.0
200	21.5	22.0
205	20.0	20.0
208	23.0	23.0
219	22.0	22.0
226	25.0	24.0
228	26.0	26.0
235	26.0	25.0
239	27.0	27.0
240	28.0	28.0
242	23.0	24.0
244	25.5	26.0
250	27.0	27.0
251	27.0	27.0
253	27.0	27.0
255	28.0	28.0
287	34.0	33.0

155 to 290 millimeters in total length were stocked individually in glass aquaria. These aquaria had aluminum frames, glass sides and bottoms and a capacity of 15 gallons. In these tests each equarium contained 12 gallons of water. These aquaria were set up on especially designed tables as shown in Figure 6. Each aquarium was aerated with compressed air throughout the 4.5-month test period. The water in the aquaria was changed every two weeks when the water temperature was below 80°F., and every 5 to 7 days when the temperature was higher. The water in all aquaria contained

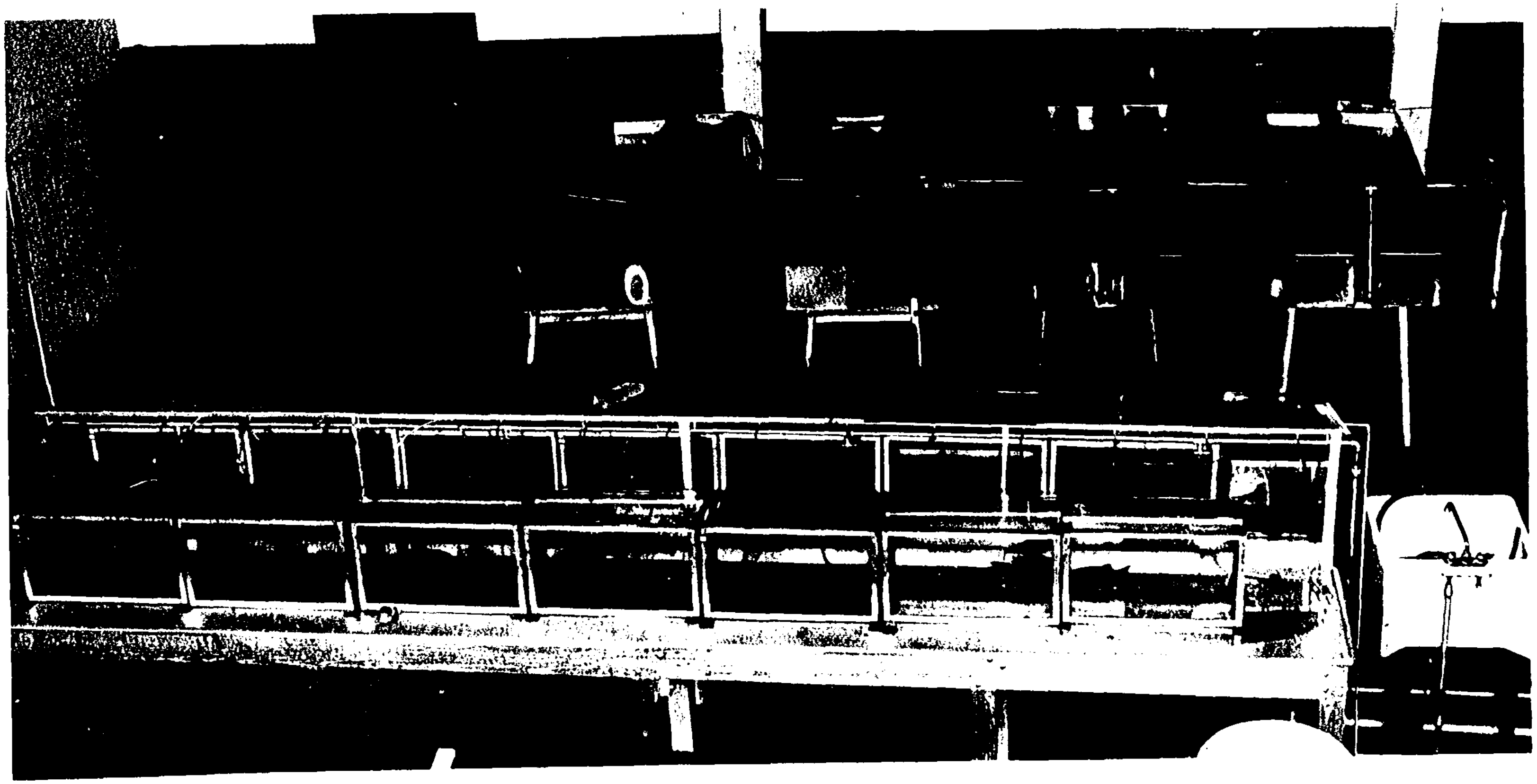

Figure 6. Table with aquaria containing bass used in feeding tests. The air and water supply pipes are located beneath the shelf in the center of the table.

a concentration of 0.5 parts per million acriflavin throughout the experimental period. It had been determined in previous research work in the Farm Ponds laboratory that this chemical at the concentration used would not interfere with the normal activity of the fish, and would decrease the possibility of fungal and bacterial infections.

The bass used in these tests were obtained from those fish recovered upon draining ponds F-11 and F-25 on April 19, 1954. These 29 bass were brought into the laboratory and stocked into aquaria on April 22. Prior to being placed in their respective aquaria, the total length and mouth width of each bass were determined. The bass were removed from the aquaria once each month and their total length and mouth width determined.

These bass were fed bluegills, golden shiners, or goldfish periodically, either every other day or every third day depending upon how hungry the bass appeared to be each day. After being measured, the forage fish was simply released into the aquarium with the bass. Fishes not eaten within 6 hours were removed from the aquaria. The total length and maximum depth of body of the forage fish fed each bass were recorded separately. A note was made on whether each forage fish was eaten or rejected by the bass.

Field Application of Relationships of Mouth Width of Bass to Maximum Depth of Body of Forage Fishes in Fisheries Management

The third phase of this investigation was concerned with the application of the information obtained from the two previous phases of research. To demonstrate the application of this information the fish population from a 1.4 acre pond was used. Complete data concerning the species, sizes, numbers, and weights of the population were obtained by completely draining the pond and collecting all of the fish present. After the fish were collected from the pond, they were placed in 500 gallon concrete tanks. Fresh stream water was run through the tanks to keep the fish alive. The fish were then removed from these tanks and sorted into species.

In the case of the largemouth bass all of the individuals from the pond were separated into inch-groups based upon their total length. The individuals in each inch-group were then counted and their total weight determined. An inch-group is that interval of total length between -0.5 and 0.5 for a given inch. For example, the 6 inch-group includes the distance 5.51 through 6.50 inches.

In securing the data on the forage fishes a slightly different procedure from that used on the largemouth bass was followed. After the forage fishes were separated into species, all individuals greater than 5.5 inches in total length were individually measured and placed into their respective inch-groups and weighed. All fish of the same species less than 5.5 inches in total length were placed together and several representative samples (totaling approximately 2 percent of the total number of small individuals) were taken. These samples were then measured and placed into their respective inch-groups. The individuals in each sample inch-group were then counted and their total weight determined. From these sample data the composition of forage fishes less than 5.5 inches total length was determined.

All computations throughout the study were triple-checked by recomputing the data.

RESULTS AND DISCUSSION

The results of this investigation will be presented in the same order as that used to describe methods of securing data. The headings under which these various phases of research will be discussed are as follows:

1. Relationships of body measurements
2. Sizes of forage fishes a largemouth bass can swallow
3. Field application of relationships of mouth width of bass to maximum depth of body of forage fishes in fisheries management.

Each of the above mentioned phases of the investigation will be summarized before continuing to the next, since each following phase will be based upon inferences from the previous one.

Relationships of Body Measurements

The relationships of body measurements will be presented by species, that is, for largemouth bass, for bluegills, for redear sunfish, for green sunfish, for golden shiners, and for goldfish.

Largemouth bass

Measurements of largemouth bass, as described in the previous section, were made on 1377 individuals ranging in size from 31 to 595 millimeters in total length. These largemouth bass specimens were collected from 37 different pond populations. The area of these ponds ranged from 0.25 to approximately 30 acres. Information concerning these pond populations is given in Table 2, and the size distribution of the largemouth bass within a pond population is given in Table 3.

Table 2. Population data for largemouth bass

Pond	Pond area acres	Stocking rate, per acre	Date stocked	Date drained	Total length Min. mm.	Max. mm.	No. indiv. in sample
F-8	0.25	100	5-11-51	6-6-52	35	290	28
F-9	0.25	150	5-11-51	6-5-52	46	276	24
F-11	0.25	150	5-11-51	6-10-52	40	295	35
F-12	0.25	100	5-11-51	6-4-52	46	291	24
F-13	0.25	100	5-11-51	6-4-52	41	310	22
F-14	0.25	200	5-8-50	4-18-51	142	189	22
F-15	0.25	150	5-11-51	6-4-52	211	248	14
F-16	0.25	100	5-8-50	4-18-51	246	291	19
F-18	0.25	100	5-11-51	6-3-52	284	324	10
F-19	0.25	100	5-11-51	6-3-52	249	302	17
F-20	0.25	150	5-11-51	6-3-52	241	293	20
F-22	0.25	200	5-8-50	4-17-51	180	207	3
F-24	0.25	100	5-11-51	6-3-52	245	319	18
F-25	0.25	100	5-11-51	6-2-52	217	305	17
F-26	0.25	100	5-11-51	6-2-52	34	290	21
F-27	0.25	100	5-11-51	6-5-52	41	311	24
F-13-25*	0.25 ea.	200	5-30-53	4-9-54	156	290	86
S-9	3.5	100	1-27-50	1-18-54	168	422	52
S-14	12.4	125	5-11-51	3-12-53	152	400	20
S-18	1.0	80	3-30-53	6-25-53	42	115	102
S-6	26.0	100	5-7-47	Spr.'53	120	470	42
S-1	22.0	100	6-10-47	Spr.'53	265	506	13
F-18 etc.*	0.25 ea.	50	6-11-52	3-6-53	221	432	30
S-11	2.6	100	4-20-49	11-15-50	155	400	59
S-12	2.2	100	4-20-49	11-20-50	347	390	31
E-8	1.0	100	4-30-49	9-18-51	230	410	34
E-6	1.0	100	4-20-49	10-18-51	253	370	26
S-4	1.3	100	1-3-49	10-10-50	120	318	40
S-8	10.7	100	4-20-49	11-8-50	59	468	155
F.P.4	1.4	100	5-11-51	10-23-52	75	383	128
E-7	1.0	100	4-20-49	11-2-51	270	423	20
S-14	12.4	125	5-30-51	9-24-53	141	217	14
S-14	12.4	125	5-30-51	9-23-53	136	213	20
S-14	12.4	125	4-20-49	11-18-50	182	424	65
L.Creek	Unknown		unknown	9-29-52	317	569	10
Delos	"		"	10-6-52	354	595	12
F-3 etc.*	0.25 ea.	100	5-11-51	6-9-52	31	336	100

*Consolidated data from ponds in replicated experiments.

Table 3. Size distribution of largemouth bass within each of 37 pond populations.

Pond	Number of largemouth black bass within each 100 millimeter interval of total length 0-100	100-199	200-299	300-399	400-499	500-599	Total N
F-8	14	1	13	-	-	-	28
F-9	15	-	9	-	-	-	24
F-11	15	1	19	-	-	-	35
F-12	9	-	15	-	-	-	24
F-13	14	-	5	3	-	-	22
F-14	-	22	-	-	-	-	22
F-15	-	-	14	-	-	-	14
F-16	-	-	19	-	-	-	19
F-18	-	-	7	3	-	-	10
F-19	-	-	14	3	-	-	17
F-20	-	-	20	-	-	-	20
F-22	-	2	1	-	-	-	3
F-24	-	-	12	6	-	-	18
F-25	-	-	9	8	-	-	17
F-26	14	1	6	-	-	-	21
F-27	14	-	5	5	-	-	24
F-13-25*	-	33	53	-	-	-	86
S-9	-	10	34	6	2	-	52
S-14	-	12	7	-	1	-	20
S-18	99	3	-	-	-	-	102
S-6	-	16	-	8	18	-	42
S-1	-	-	1	-	11	1	13
F-18 etc.*		-	25	2	3	-	30
S-11	-	21	4	33	1	-	59
S-12	-	-	-	31	-	-	31
E-8	-	-	19	10	5	-	34
E-6	-	-	23	3	-	-	26
S-4	-	20	16	4	-	-	40
S-8	81	30	20	20	4	-	155
F.P.4	54	48	-	26	-	-	128
E-7	-	-	4	14	2	-	20
S-14	-	13	1	-	-	-	14
S-14	-	19	1	-	-	-	20
S-14	-	3	23	38	1	-	65
L Creek	-	-	-	2	6	2	10
Delos	-	-	-	1	4	7	12
F-3 etc.*	41	-	48	11	-	-	100

*Consolidated data from ponds in replicated experiments.

The linear regression of mouth width on total length of largemouth bass for each of the 37 populations was determined. These regression coefficients, standard deviations (s), and correlation coefficients (r) are given in Table 4. The homogeneity of the regression coefficients (Goulden, 1952, p. 158-159) for the 37 pond populations of largemouth bass was tested by analysis of covariance. Using actual values of measurements the following analysis was obtained.

	D.F.	S.S.	M.S.	F
Total	1339	26,963		
Populations	1303	17,688	13.58	
Difference	36	9,275	257.64	18.98

With logarithmic values of measurements the following analysis was obtained;

	D.F.	S.S.	M.S.	F
Total	1339	6.605380		
Populations	1303	5.244422	.004025	
Difference	36	1.360958	.037804	9.39

At a P = .01 the tabular F is 1.60 with $N_1 = 36$ and $N_2 = 1303$ degrees of freedom. The calculated F's obtained in these analyses are highly significant, thus the regression coefficients for the pond populations of largemouth bass were heterogeneous.

Since the primary purpose of this investigation of the relationships of body measurements of bass was to provide estimating equations for predicting mouth width from total length, it was deemed necessary to disregard the heterogeneous nature of the regression coefficients and combine all of the measurement data from these 37 pond populations of largemouth bass. This would permit the calculation of prediction equations

Table 4. Regression coefficients, standard deviations from regression, and correlation coefficients for relationship of mouth width to total length of largemouth bass in each of 37 populations, determined from actual and logarithmic values of measurement data.

Pond	N	Actual values			Logarithmic values		
		b	s	r	b	s	r
F-8	28	.101	0.82	.9975	.8870	.1058	.9955
F-9	24	.096	1.17	.9930	.9042	.1249	.9925
F-11	35	.108	1.87	.9884	.9500	.1072	.9950
F-12	24	.104	1.48	.9925	.9319	.0266	.9970
F-13	22	.104	1.30	.9950	.8716	.1122	.9951
F-14	22	.107	0.93	.8378	1.1131	.0267	.8044
F-15	14	.156	1.15	.8497	1.6118	.0227	.8480
F-16	19	.046	3.00	.4750	.3000	.1216	.3924
F-18	10	.224	1.69	.8723	1.7250	.0193	.8645
F-19	17	.220	0.63	.9750	1.1214	.0303	.7043
F-20	20	.202	1.23	.8790	1.8850	.0195	.8712
F-22	3	.220	0.55	.9940	2.0301	.0057	.9980
F-24	18	.178	2.39	.7887	1.4587	.0292	.7981
F-25	18	.120	2.99	.7694	1.2179	.1396	.8006
F-26	21	.099	0.94	.9960	.9156	.0300	.9965
F-27	24	.108	1.67	.9930	.9781	.1166	.9960
F-13&25	86	.144	1.36	.9742	1.3102	.0229	.9783
S-9	52	.160	1.69	.9848	1.3302	.0234	.9829
S-14	20	.144	0.98	.9938	1.3082	.0187	.9920
S-18	120	.104	0.41	.9434	1.0067	.1000	.9088
S-6	42	.141	5.92	.9550	1.2296	.2600	.7335
S-1	13	.200	5.23	.9171	1.4928	.1095	.9497
F-18	30	.151	3.31	.9225	1.2211	.1205	.9165
S-11	59	.147	1.95	.9875	1.4410	.0287	.9904
S-12	31	.133	2.57	.5263	1.2388	.0284	.5244
E-8	34	.124	2.55	.9669	1.0440	.0295	.9680
E-6	26	.167	2.59	.8497	1.5217	.0210	.9317
S-4	40	.135	1.99	.9787	1.6324	.1462	.9828
S-8	155	.100	7.25	.8479	.9369	.0183	.9783
F.P.4	128	.124	1.35	.9944	1.1281	.0235	.9960
E-7	20	.147	2.61	.9348	1.2816	.0266	.9450
S-14	14	.143	1.27	.9220	1.1921	.0309	.8983
S-14	19	.156	1.18	.9257	1.2812	.0277	.9088
S-14	65	.129	2.83	.9497	1.1757	.1118	.9597
L.C.	10	.159	4.34	.9420	1.0726	.1034	.9274
Delos	12	.186	6.80	.8798	1.2313	.1245	.8916
F-3	100	.104	1.27	.9930	.9044	.1053	.9586

which would cover practically the entire range of total length for this species of fish. It was also assumed that such combined data would give estimates of the variations which might be expected in individuals of this species from different habitats.

The 1377 largemouth bass were combined and then arranged in numerical order, starting with the smallest and proceeding to the largest, based upon their total length. The individuals were then divided into 10 millimeter intervals of total length. The mean mouth width was determined for each of the interval groups. The 1377 bass were also separated into inch-groups based upon their total length and the mean mouth width for each of these inch-groups was determined. In each separation the mid point of the total length interval was used to represent the group. The means for each of the various groups are given in Table 5.

The mean mouth width of bass (per 10 millimeter interval of total length) was plotted against total length using actual and logarithmic values of the data. On each plot only slight curvilinear trends were evident over each 100 millimeter interval of total length, but a distinct curvilinear trend was evident over the entire range from 31 to 595 millimeters in total length. These two plots exhibited such similar curves that it was impossible to determine visually if actual or logarithmic values of measurement data would give the best prediction equations. Also due to the curvilinear trends it appeared that no single prediction equation would give accurate estimates of mouth widths over the entire total length range.

It would not be amiss to assume that this curvilinear trend of the relationship of mouth width to total length of bass was largely responsible for the heterogeneity of pond populations regression coefficients.

Table 5. Mean maximum depth of body and mouth width for each given total length interval determined from 1377 specimens of largemouth bass.

Total length In.	Total length Mm.	N	Maximum depth of body Mm.	Mouth width Mm.
1	(25)	21	7.0	4.4
	35	22	7.0	4.4
	45	97	9.3	5.4
2	(51)	212	10.2	5.7
	55	95	10.8	5.8
	65	60	12.9	7.1
	75	45	14.4	7.6
3	(76)	106	14.5	7.6
	85	20	17.3	8.6
	95	32	18.8	9.4
4	(102)	52	19.3	9.6
	105	16	21.0	10.3
	115	9	23.1	11.7
	125	10	24.6	11.4
5	(127)	29	25.9	12.2
	135	14	27.8	13.0
	145	47	29.7	14.0
6	(152)	119	31.1	14.8
	155	53	32.1	15.2
	165	29	35.0	16.8
	175	30	36.2	17.0
7	(178)	64	37.0	17.2
	185	21	38.9	17.9
	195	26	41.5	19.2
8	(203)	61	43.5	20.7
	205	22	44.0	21.2
	215	24	46.2	21.9
	225	23	49.4	23.8
9	(229)	79	51.3	24.8
	235	36	52.4	25.2
	245	57	55.5	26.5
10	(254)	117	55.3	25.8
	255	42	55.2	26.0
	265	54	59.9	27.3
	275	81	63.3	30.4
11	(279)	185	64.1	30.7
	285	53	66.5	31.8
	295	54	68.9	33.4
	305	37	71.6	34.4

Table 5. (Continued)

Total length In.	Mm.	N	Maximum depth of body Mm.	Mouth width Mm.
12	(305)	76	70.9	34.1
	315	13	71.8	35.9
	325	7	73.3	37.7
13	(330)	31	78.7	38.7
	335	8	79.8	38.1
	345	28	79.8	38.7
	355	37	83.1	40.9
14	(356)	89	83.9	40.3
	365	41	86.4	40.6
	375	27	88.8	41.9
15	(381)	65	89.8	42.4
	385	27	89.4	41.6
	395	12	95.1	46.6
	405	14	102.6	51.6
16	(406)	24	101.8	51.2
	415	7	101.6	51.7
	425	13	104.6	53.1
17	(432)	23	106.8	55.0
	435	9	110.1	57.7
	445	1	105.0	55.0
	455	5	109.2	55.4
18	(457)	9	118.4	58.2
	465	3	130.3	65.3
	475	1	130.0	60.0
19	(483)	4	134.0	68.0
	485	2	134.5	68.5
	495	3	132.3	67.7
	505	2	128.0	73.0
20	(508)	4	132.0	69.8
	515	1	140.0	65.0
	524	1	147.0	83.0
21	(533)	3	147.7	79.3
	535			
	545	3	152.0	80.3
	555			
22	(559)	3	160.3	83.3
	565	1	150.0	85.0
	575	1	171.0	79.0
23	(584)	1	178.0	98.0
	595	1	178.0	98.0

Several of the populations had rather narrow ranges of total length and the ranges from different ponds fell on different portions of the curve. Five ponds (F-8, 9, 11, 12, and 26) had bass in the first three size ranges and the regression coefficients appear to be quite homogeneous (.101, .096, .108, .104, and .099, respectively). Five ponds (S-9, 14, 6, 11, and 14) had bass in the size ranges 100-499 and the regression coefficients again appear quite homogeneous (.160, .144, .141, .147, and .129, respectively). Five ponds (F-18, 19, 24, 25, and E-6) had bass in the size range 200-399. The regression coefficients (.224, .220, .178, .120, and .167, respectively) do not appear to be as homogeneous as in the other examples. Four ponds (F-13, 27, F.P. 4, and F-3) had bass in the first four size ranges, and the regression coefficients appear quite homogeneous (.104, .108, .124, and .104, respectively).

These apparent homogeneous and heterogeneous groups of regression coefficients were tested by analyses of covariance. The results of these analyses are summarized below:

Pond groups	Homogeneous regression coefficients for range groups					
	31-595 mm.	less 100 mm.	100-199 mm.	200-299 mm.	300-399 mm.	400-499 mm.
F-8,9,11,12,26	No	Yes		Yes(*)		
S-9,14,16,11,14	Yes		Yes	Yes(*)	No	Yes(*)
F-18,19,24,25,E-6	Yes			Yes	Yes	
F-13,27,F.P.4,F-3	No	Yes		Yes(*)	Yes(*)	

The (*) by the results of the analyses of covariance test indicates that the mean squares of deviation within the populations were greater than the mean squares of deviations for differences between populations.

The homogeneity of the regression coefficients for all populations of bass represented in each 100 millimeter interval group was also tested by analysis of covariance. In the less than 100 millimeter group the regression coefficients were homogeneous for 11 populations of bass (F-3, 8, 9, 11, 12, 13, 26, 27, S-8, 18, and F.P.4). For the 100-199 millimeter group the regression coefficients were heterogeneous for the 17 populations of bass (F-8, 11, 14, 22, 26, 13-25, S-4, 18, 6, 8, 9, 11, 14, 14, 14, 14, and F.P.4). In the 200-299 millimeter group the regression coefficients were heterogeneous for 30 populations of bass (E-8, 7, 6, S-4, 1, 8, 11, 14, 14, 14, 14, 9, F-3, 18, 8, 9, 11, 12, 13, 15, 16, 18, 19, 20, 22, 24, 25, 26, 27, 13-25). In the 300-399 millimeter group the regression coefficients were heterogeneous for 21 populations of bass (E-8, 7, 6, S-4, 6, 8, 11, 14, 9, 12, F.P.4, F-3, 18, 13, 18, 19, 24, 25, 27, L.C., and Delos). In the 400-499 millimeter group the regression coefficients were homogeneous for 12 populations of bass (E-8, 7, S-1, 6, 8, 11, 14, 14, 9, F-18, L.C., and Delos). For the 500-595 millimeter group the regression coefficients were homogeneous for the 3 populations (S-1, L.C., and Delos).

It appears that the heterogeneity of regression coefficients of the various groups was at least partly the result of comparing populations with different size ranges. Schaefer (1952) believed that the lack of homogeneity among samples of fish from supposedly the same population was possibly caused by differences in total length ranges for the various samples. In those cases where the mean squares of deviations within populations were greater than mean squares of deviations between populations, the causes of heterogeneity may have been due to errors in original measurements, the narrow range of total length within a size group for a population, the use of only approximate regression equations, or to genetic differences of individuals as proposed by Schaefer (1952). Even though the majority of bass used in this study were progeny of stock maintained by the Farm Ponds Project for the past 15 years, they would still be considered wild, unselected bass.

Prediction equations for the relationships of total length to mouth width of largemouth bass with accompanying standard deviations (s), correlation coefficients (r), coefficients of variation (c), and standard errors of the regression coefficients (s_b) were determined from actual and from logarithmic values of measurement data for the following total length intervals:

1. The entire range from 31 through 595 millimeters
2. From 100 through 595 millimeters
3. From 31 through 99, from 100 through 199, from 200 through 299, from 300 through 399, from 400 through 499, and from 500 through 595 millimeters.

The prediction equations for each of the separations with their accompanying estimators determined from actual and logarithmic values of measurement data are given in Tables 6 and 7.

Graphically the lines representing the prediction equations determined from actual values of measurement data are shown in Figure 7, and lines representing prediction equations determined from logarithmic values of measurement data are shown in Figure 8. A comparison of the linear relationships shown in these two figures emphasizes the similarity of the equations obtained from actual and from logarithmic values of the measurement data. These graphs also illustrate the inability of any single linear

Table 6. Estimating equations for determining mouth width of largemouth bass from total length, determined from actual measurement data.

Range	Estimating equation	Std. dev. ±	r	C	Std. error of b ±
31 - 595	M = -2.39 + 0.1222L	3.74	.968	16.0	.000836
100 - 595	M = -7.26 + 0.1383L	3.94	.951	13.3	.00141
31 - 99	M = 1.88 + 0.0775L	0.68	.883	10.4	.00266
100-199	M = -0.98 + 0.1043L	2.13	.764	14.0	.00557
200 - 299	M = -7.03 + 0.1358L	3.21	.737	11.5	.00592
300 - 399	M = -2.84 + 0.1212L	4.39	.606	11.1	.0104
400 - 499	M = -19.99 + 0.1755L	5.47	.654	9.85	.0271
500 - 595	M = -50.77 + 0.2405L	6.42	.768	8.1	.0707

Table 7. Estimating equations for determining mouth width of largemouth bass from total length, determined from logarithmic values of measurement data.

Range mm.	Estimating equations	Std. dev. ±	r	C	Std. error b ±
31-595	logM = -0.9938 + 1.0120 logL	.0633	.9627	5.0	.0017
100-595	LogM = -1.4582 + 1.2034 logL	.0446	.9726	3.1	.0092
31-99	logM = -0.5222 + 0.7518 logL	.0453	.8907	5.6	.0200
100-199	logM = -0.8623 + 0.9303 logL	.0758	.6842	6.5	.0623
200-299	logM = -1.6031 + 1.2633 logL	.0523	.9078	3.6	.0554
300-399	logM = -0.8347 + 0.9553 logL	.0423	.6202	2.6	.0788
400-499	LogM = -2.0435 + 1.4362 logL	.0451	.6422	2.6	.2272
500-595	logM = -3.0377 + 1.8057 logL	.0294	.8433	1.6	.4070

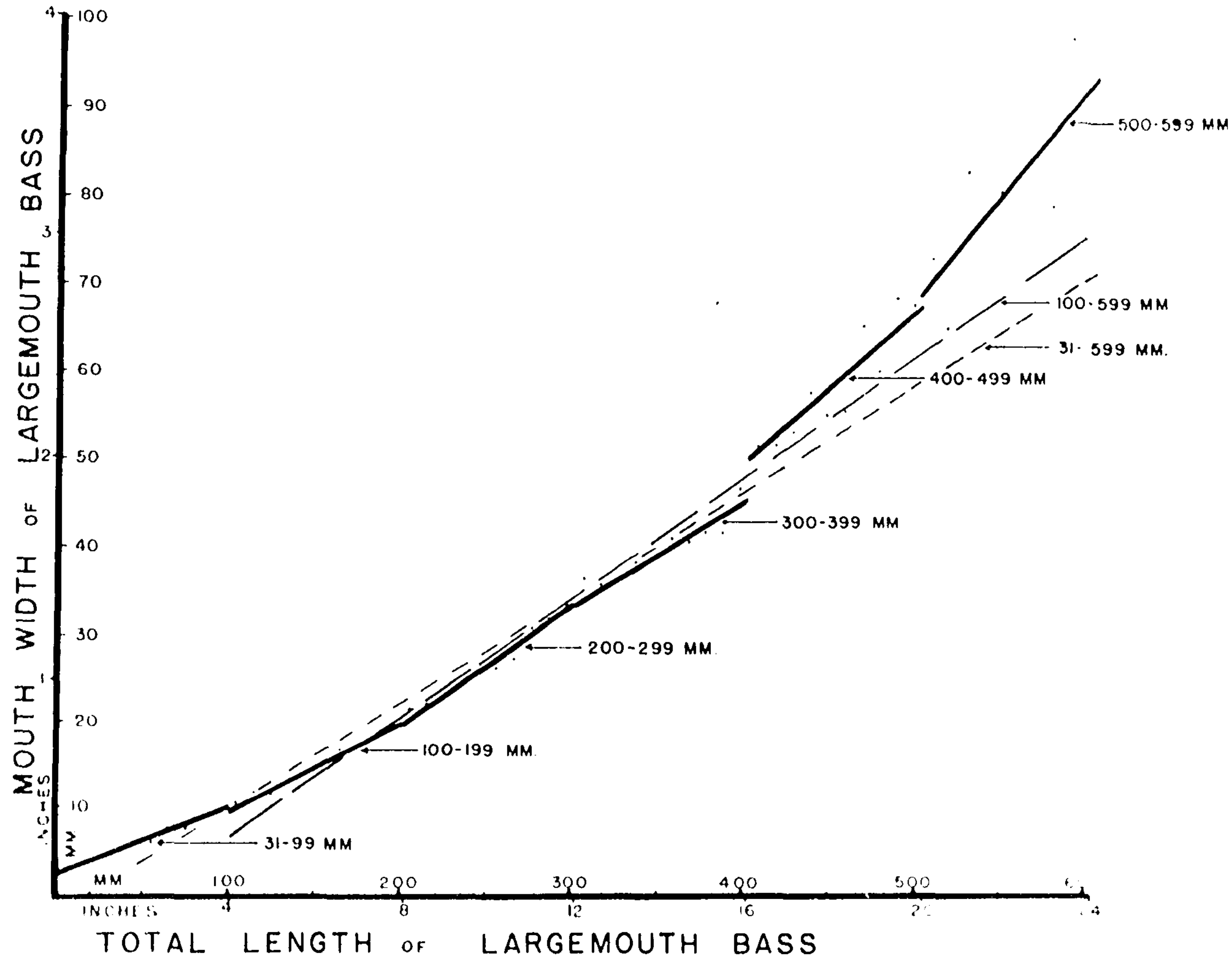

Figure 7. Estimated mouth widths of largemouth bass of given total length as determined from equations given in Table 6.

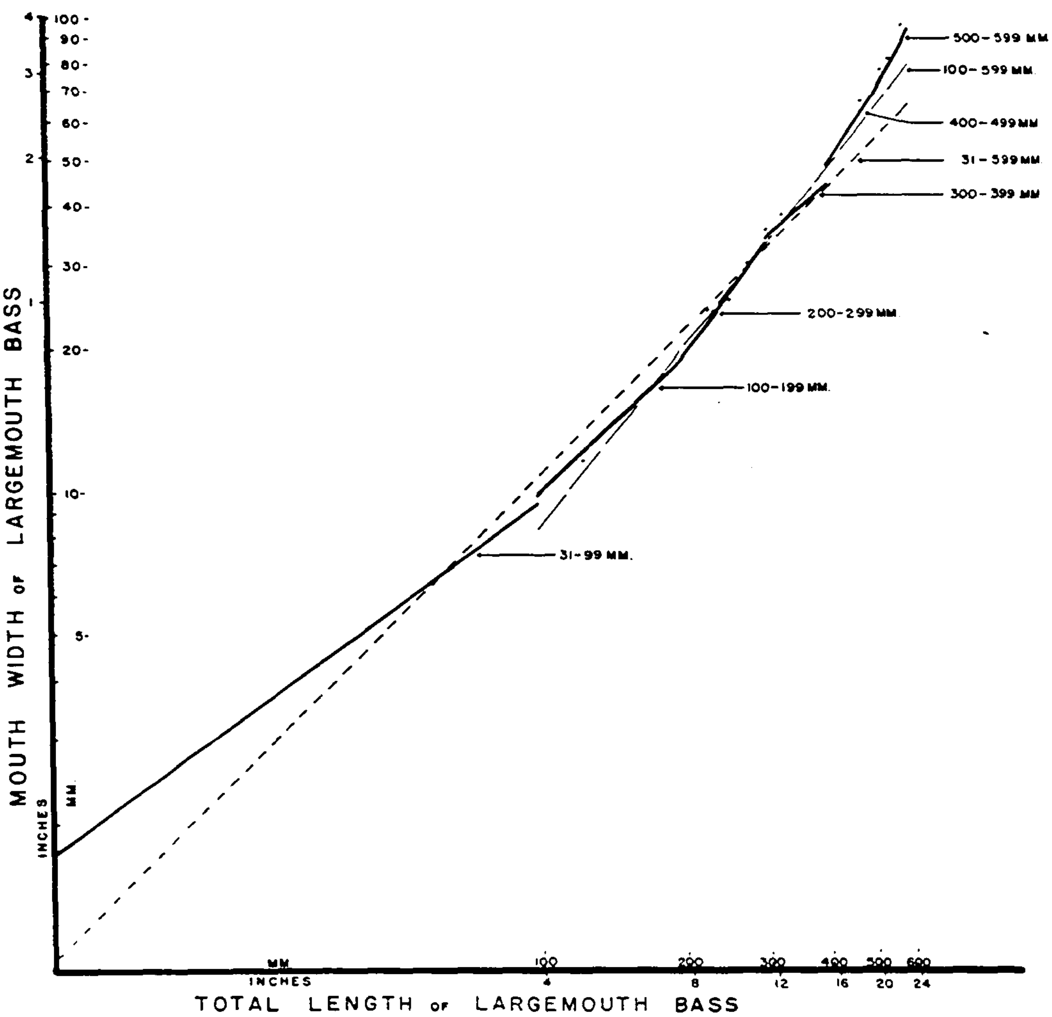

Figure 8. Estimated mouth widths of largemouth bass of given total length as determined from equations given in Table 7.

equation to give reliable mouth width estimates over the entire range of total length of bass.

The ability of the equations given in Tables 6 and 7 to estimate the mouth width of bass was tested using the mean mouth width data given in Table 5. The equation used to determine the difference between mean and estimated values was as follows:

$$(\hat{M}/\bar{M} \times 100) - 100 = \text{percent difference.}$$

The calculated differences, expressed as percentages, are summarized in Tables 8, 9, and 10. These differences indicated that none of the equations, determined from actual nor logarithmic values of measurements for either the entire or 100 through 595 millimeter range, gave usable estimates of mouth width near the extremes of the total length range. Fairly usable estimates of mouth widths of bass were obtained by using 100 millimeter total length intervals estimating equations determined from either actual or logarithmic values of measurements. These evaluations of the estimates by using the differences between mean and estimated values may not be entirely valid, particularly at the extremes of the prediction equations ranges. Such difficulties arose from the unequal distribution of individuals within each inch-group of total length. In some instances a majority of the individuals were near one extreme for that group. Thus the means for the inch-groups may be somewhat in error. However, this technique was believed to be sufficiently accurate to indicate the ability of the various regression equations to estimate the mouth width of bass from their total length.

Tests, employing analysis of covariance, were performed to determine if the regression coefficients of the 100 millimeter total length interval

Table 8. Differences, as percentages of means, between mean mouth widths for largemouth bass and values estimated by a linear regression from 31 through 595 millimeters of total length.

Total length: Inch-group	Total length: Inch-group mean Mm.	N	Mean mouth width Mm.	Deviations of estimated mouth width as percentage of means: Actual data	Logarithmic data
1	34.5	21	4.4	-59.4	-18.2
2	51.0	212	5.7	-32.6	-5.3
3	72.9	106	7.6	-14.2	2.6
4	99.7	52	9.6	2.0	11.4
5	127.3	29	12.2	8.0	12.3
6	151.7	119	14.8	9.1	10.8
7	177.0	64	17.2	11.8	11.0
8	203.0	61	20.7	8.3	6.3
9	230.5	79	24.8	4.0	0.8
10	253.8	117	25.8	10.9	6.6
11	279.1	185	30.7	3.3	-1.4
12	302.1	76	34.1	1.3	-3.2
13	335.0	31	38.7	-0.4	-5.7
14	356.2	89	40.3	2.1	-3.7
15	379.2	65	42.4	3.7	-2.6
16	404.2	24	51.2	-8.2	-13.9
17	428.7	23	55.0	-9.1	-14.9
18	459.4	9	59.2	-9.2	-14.2
19	489.5	4	68.0	-15.5	-21.3
20	505.3	4	69.8	-15.0	-20.7
21	539.0	3	79.3	-20.0	-25.6
22	562.7	3	83.3	-20.3	-26.0
23	595.0	1	98.0	-28.2	-33.5

Table 9. Differences, as percentages of means, between mean mouth width for largemouth bass and values estimated by linear regression from 100 through 595 millimeters of total length.

Total length: Inch-group	Total length: Inch-group mean Mm.	N	Mean mouth width Mm.	Deviations of estimated mouth width as percentage of means: Actual data	Deviations of estimated mouth width as percentage of means: Logarithmic data
5	127.3	29	12.2	-15.2	-2.5
6	151.7	119	14.8	-7.3	-0.7
7	177.0	64	17.2	0.0	2.9
8	203.0	61	20.7	0.5	0.5
9	230.5	79	24.8	- 0.7	-2.0
10	253.8	117	25.8	7.9	5.4
11	279.1	185	30.7	2.1	-0.4
12	302.1	76	34.1	1.2	-1.5
13	335.0	31	38.7	1.0	-1.6
14	356.2	89	40.3	4.2	1.7
15	379.2	65	42.4	6.6	4.2
16	404.2	24	51.2	-5.0	-6.8
17	428.7	23	55.0	-5.4	-6.9
18	459.4	9	59.2	-4.9	-5.9
19	489.5	4	68.0	-11.1	-11.6
20	505.3	4	69.8	-10.3	-10.6
21	539.0	3	79.3	-15.2	-14.9
22	562.7	3	83.3	-15.3	-14.8
23	595.0	1	98.0	-23.4	-22.4

Table 10. Differences, as percentages of means, between mean mouth width for largemouth bass and values estimated by a linear regression by 100 millimeter intervals of total length.

Total length: Inch-group	Total length: Inch-group mean Mm.	N	Mean mouth width Mm.	Deviations of estimated mouth width as percentage of means: Actual data	Deviations of estimated mouth width as percentage of means: Logarithmic data
1	34.5	21	4.4	3.4	0.0
2	51.0	212	5.7	2.3	1.8
3	72.9	106	7.6	-1.0	0.0
4	99.7	52	9.6	0.0	0.0
5	127.3	29	12.2	0.8	2.5
6	151.7	119	14.8	0.3	-0.7
7	177.0	64	17.2	1.6	-1.8
8	203.0	61	20.7	-0.8	-1.0
9	230.5	79	24.8	-2.1	-2.8
10	253.8	117	25.8	6.4	5.4
11	279.1	185	30.7	0.6	0.0
12	302.1	76	34.1	-1.0	0.3
13	335.0	31	38.7	-2.4	-2.3
14	356.2	89	40.3	0.0	-0.5
15	379.2	65	42.4	1.7	0.2
16	404.2	24	51.2	-0.5	-2.1
17	428.7	23	55.0	0.5	-0.7
18	459.4	9	59.2	2.4	1.9
19	489.5	4	68.0	-3.0	-2.9
20	505.3	4	69.8	1.4	0.0
21	539.0	3	79.3	-0.6	0.3
22	562.7	3	83.3	1.5	1.8
23	595.0	1	98.0	-5.8	-4.3

groups were homogeneous. Using actual values of measurements and including all six interval groups, the following analysis was obtained:

	D.F.	S.S.	M.S.	F
Total	1370	12,991.7		
Groups	1365	12,457.3	9.48	
Difference	5	534.4	106.89	11.28

With logarithmic values of measurements and including all six interval groups, the following analysis was obtained:

	D.F.	S.S.	M.S.	F
Total	1370	4.203762		
Groups	1365	3.971107	.003068	
Difference	5	.232655	.046531	15.17

At a $P = .01$ the tabular F is 3.03 with $N_1 = 5$ and $N_2 = 1365$ degrees of freedom, thus the calculated F's in both of the above analyses are highly significant.

Since it was suspected that bass less than 100 millimeters in total length had a regression coefficient different from the bass of greater length, analyses of covariance were used on the five interval groups whose total length was greater than 100 millimeters. Using actual values of measurements the following analysis was obtained:

	D.F.	S.S.	M.S.	F
Total	1001	12,584.4		
Groups	997	12,281.9	12.57	
Difference	4	302.5	75.63	6.02

With logarithmic values of measurements the following analysis was obtained:

	D.F.	S.S.	M.S.	F
Total	1001	3.291095		
Groups	997	3.217855	.003288	
Difference	4	.073240	.018310	5.57

At a $P = .01$ the tabular F is 3.34 with $N_1 = 4$ and $N_2 = 997$ degrees of freedom, thus by eliminating the bass less than 100 millimeters in total length the calculated F's were reduced in value. However, they are still sufficiently high to indicate a highly significant heterogeneity in the regression coefficients of the groups.

The results obtained in the analyses of the 100 millimeter interval groups indicate that it is very unlikely that a single linear equation could closely fit any group of bass, whose total length ranged from 31 to 595 millimeters. Thus statistical information is available to substantiate the choice of estimating equations for 100 millimeter total length intervals to predict the mouth width of largemouth bass.

The effort to approximate, with a descriptive equation, the relation of mouth width to total length over the total length range from 31 to 595 millimeters was not satisfied by either the rectilinear or allometry equation already employed. Thus it can be stated that the relation of mouth width to total length of bass does not exhibit either linear or allomorphic type of growth except for limited intervals of growth.

Two curvilinear types of equations were tried, using the mean mouth width data given in Table 5, to determine how well these curves would approximate the relation of mouth width to total length of bass for the entire range of total length from 31 to 595 millimeters. The abilities of the polynomial and Godsil (1948) type equation to estimate the mouth width of bass for each inch-group of total length, as percent difference from means, are given in Table 11. It is readily apparent that the polynomial equation gives a much better approximation to the relation than did either the rectilinear or allometry equation for the entire range of total length, but does not give as good approximations as were obtained by the 100 millimeter interval linear equations. Except for a limited interval of total length of bass, the Godsil equation gave a very unsatisfactory approximation to the relation of mouth width to total length. These results emphasize the

Table 11. Differences, as percentages of means, between mean and estimated values* of mouth width for largemouth bass from 31 through 595 millimeters of total length.

Total length In.	Total length Mean Mm.	Mean mouth width Mm.	Estimated mouth width as a percentage of mean: Polynomial eq.	Estimated mouth width as a percentage of mean: Godsil's eq.
2	51.0	5.7	21.0	335.0
3	72.9	7.6	7.9	161.8
4	99.7	9.6	4.2	93.7
5	127.3	12.2	0.0	59.0
6	151.7	14.8	-3.4	41.2
7	177.0	17.2	-2.3	33.1
8	203.0	20.7	-5.3	22.7
9	230.5	24.8	-7.7	13.7
10	253.8	25.8	0.4	19.0
11	279.1	30.7	-4.6	9.1
12	302.1	34.1	-4.1	6.1
13	335.0	38.7	-2.1	3.4
14	356.2	40.3	3.0	5.5
15	379.2	42.4	7.3	6.8
16	404.2	51.2	-2.0	-5.5
17	428.7	55.0	0.0	-6.5
18	459.4	59.2	3.5	-6.8
19	489.5	68.0	-0.1	-13.4
20	505.3	69.8	2.4	-12.8
21	539.0	79.3	0.1	-18.0
22	562.7	83.3	2.4	-18.2
23	595.0	98.0	-4.4	-26.4

*Polynomial equation: $M = 4.69 + 0.0342L + 0.00019387L^2$; Godsil's equation: $M = -7.56 + 0.130294L + 1314.02/L$.

the fact that these bass exhibit stanzas of growth with sharp inflections which can be very well approximated by a series of linear equations.

The regression of maximum depth of body on total length of largemouth bass for each of the 37 populations was determined. These regression coefficients, standard deviations (s), and correlation coefficients (r) are given in Table 12. The homogeneity of the regression coefficients for the 37 populations of bass was tested by analysis of covariance. Using actual values of measurements the following analysis was obtained:

	D.F.	S.S.	M.S.	F
Total	1339	18,308.801		
Populations	1303	14,362.031	11.022	
Difference	36	3,946.770	109.633	9.95

With logarithmic values of measurements the following analysis was obtained:

	D.F.	S.S.	M.S.	F
Total	1339	1.038529		
Populations	1303	.870958	.0006684	
Difference	36	.167571	.0046547	6.96

The calculated F's in both analyses were highly significant, thus the regression coefficients for the different populations of bass were heterogeneous.

The heterogeneous nature of these regression coefficients was again disregarded and all of the data from the 37 populations of bass were combined for the same reasons as stated previously. These combined data were arranged in numerical order, and then broken into 100 millimeter interval total length groups. From these interval group data were computed prediction equations for relationship of maximum depth of body to total length with their accompanying standard deviations (s), correlation coefficients (r), coefficients of variation (c), and standard error of

Table 12. Regression coefficients, standard deviations from regression, and correlation coefficients for relationship of maximum depth of body to total length of largemouth bass in each of 37 populations determined from actual and logarithmic values of measurements.

Pond	N	Actual values			Logarithmic values		
		b	s	r	b	s	r
F-8	28	.221	2.17	.9958	1.0295	.0305	.9975
F-9	24	.213	1.98	.9953	1.0043	.0234	.9977
F-11	35	.228	2.57	.9950	1.0314	.0220	.9984
F-12	24	.232	2.83	.9942	1.0449	.0216	.9985
F-13	22	.237	2.19	.9972	1.0646	.0241	.9985
F-14	22	.219	1.24	.9056	1.0243	.0147	.9149
F-15	14	.220	2.04	.7867	1.0615	.0192	.7810
F-16	19	.163	3.38	.4313	0.6004	.0209	.4183
F-18	10	.323	3.29	.7987	1.3937	.0200	.8025
F-19	17	.240	2.99	.8081	1.0075	.0196	.8093
F-20	20	.352	2.48	.8468	1.5824	.0193	.8336
F-22	3	.330	0.30	.9990	1.4352	.0110	.9985
F-24	18	.262	2.30	.8910	1.0994	.1392	.9024
F-25	18	.241	3.85	.8792	1.2086	.2569	.9158
F-26	21	.225	2.31	.9955	1.0440	.1095	.9965
F-27	24	.239	1.49	.9988	1.0782	.2010	.9990
F-13&25	86	.277	2.56	.9756	1.2283	.0208	.9794
S-9	52	.324	3.19	.9867	1.3212	.1637	.9913
S-14	20	.333	3.36	.9864	1.3196	.2486	.9858
S-18	102	.238	0.60	.9756	1.1126	.0218	.9614
S-6	42	.267	8.87	.9711	1.1406	.0129	.9879
S-1	13	.319	2.95	.8988	1.2178	.1095	.9273
F-18	30	.287	6.45	.9192	1.1578	.1153	.9149
S-11	59	.278	3.24	.9909	1.2063	.0196	.9935
S-12	31	.296	3.42	.7197	1.2320	.0167	.7204
E-8	34	.271	3.63	.9855	1.1504	.0192	.9884
E-6	26	.311	2.17	.9632	1.3682	.0147	.9571
S-4	40	.217	2.02	.9914	1.1168	.0198	.9930
S-8	155	.252	2.62	.9960	1.1213	.1280	.9923
FP-4	128	.245	1.77	.9976	1.1113	.0197	.9971
E-7	20	.254	2.19	.9933	1.1323	.0129	.9823
S-14	14	.234	1.44	.9603	1.0990	.0186	.9524
S-14	19	.227	1.51	.9398	1.0225	.0187	.9327
S-14	65	.251	1.36	.9965	1.1338	.0194	.9864
L.C.	10	.288	6.87	.9533	1.1193	.0286	.9475
Delos	12	.355	6.90	.9612	1.2372	.0209	.9659
F-3	100	.251	4.31	.9913	1.0839	.0292	.9977

regression coefficients (s_b). Using actual values of measurements the following results were obtained:

	s	r	c	s_b
Less 100 mm. $D = 5.69 + 0.1055L$,	2.77	.5367	23.06	.0273
100-199 mm. $D = -3.78 + 0.2329L$,	1.89	.9840	5.82	.0155
200-299 mm. $D = -18.98 + 0.3012L$,	3.71	.9024	6.31	.0216
300-399 mm. $D = 3.40 + 0.2259L$,	15.81	.3674	19.18	.1180
400-499 mm. $D = -40.15 + 0.3470L$,	8.94	.7230	8.19	.1400
500-599 mm. $D = -119.13 + 0.4961L$,	6.66	.9220	4.44	.2330

With logarithmic values of measurements the following results were obtained:

	s	r	c	s_b
Less 100 mm. $\log D = -0.6223 + 0.9574 \log L$,	.0336	.9580	3.16	.0148
100-199 mm. $\log D = -0.6206 + 0.9715 \log L$,	.0338	.8843	2.25	.0278
200-299 mm. $\log D = -1.2427 + 1.2480 \log L$,	.0998	.8706	5.66	.1053
300-399 mm. $\log D = -0.8267 + 1.0778 \log L$,	.0331	.7819	1.57	.0560
400-499 mm. $\log D = -1.7408 + 1.4331 \log L$,	.0430	.7145	2.12	.2170
500-599 mm. $\log D = -2.7307 + 1.7940 \log L$,	.0187	.9225	0.86	.2590

The abilities of the regression equations to estimate the maximum depth of body of bass were tested against the mean depth for each inch-group as given in Table 5. The differences, as percentages of means, for each inch-group as determined from actual and logarithmic value equations are given in Table 13. Just as with the results on the relations of mouth

Table 13. Differences, as percentages of means, between mean maximum depth of body of largemouth bass and values estimated from linear regression by 100 millimeter intervals of total length.

Total length: Inch-group	Total length: Inch-group mean Mm.	N	Mean maximum depth body Mm.	Deviations of estimated maximum depth as percentages of means: Actual values	Deviations of estimated maximum depth as percentages of means: Logarithmic values
1	34.5	21	7.0	32.0	1.4
2	51.0	212	10.2	8.8	1.0
3	72.9	106	14.5	-7.6	0.0
4	99.7	52	19.3	-16.1	1.6
5	127.3	29	25.9	0.0	2.7
6	151.7	119	31.1	1.6	1.3
7	177.0	64	37.0	1.1	-1.1
8	203.0	61	43.5	-3.0	-0.2
9	230.5	79	51.3	-1.8	-1.0
10	253.8	117	55.3	4.0	3.6
11	279.1	185	64.1	1.6	0.6
12	302.1	76	70.9	1.0	-1.0
13	335.0	31	78.8	0.4	-0.4
14	356.2	89	83.9	0.0	0.0
15	379.2	65	89.8	-0.8	-0.1
16	404.2	24	101.8	-1.7	-3.0
17	428.7	23	106.8	1.7	1.1
18	459.4	9	118.4	0.8	0.5
19	489.5	4	134.0	-3.2	-3.0
20	505.3	4	132.0	-0.4	0.0
21	539.0	3	147.7	0.4	0.2
22	562.7	3	160.3	-0.2	-0.2
23	595.0	1	178.0	-1.1	-0.6

width to total length of bass, these differences indicate that usable estimates may be obtained using either actual or logarithmic values with the 100 millimeter interval groups estimating equations.

The homogeneity of the coefficients for linear regression of maximum depth of body on total length for 100 millimeter interval groups of bass was tested using analysis of covariance. Using actual values of measurements the following analysis was obtained:

	D.F.	S.S.	M.S.	F
Total	1370	77,485.276		
Groups	1365	73,526.848	53.866	
Difference	5	3,958.428	791.685	14.70

With logarithmic values of measurement data the following analysis was obtained:

	D.F.	S.S.	M.S.	F
Total	1370	1.646481		
Groups	1365	1.568602	.0011492	
Difference	5	.077879	.0155758	13.55

In each of these analyses the calculated F was highly significant, thus the regression coefficients for the different interval groups of bass were not homogeneous. It appears that the transformation of the measurement data to logarithms was of little or no value in producing more homogeneous linear relations between maximum depth of body and total length. However, the use of logarithm values did tend to reduce the variation in the prediction equations.

Bluegills

The bluegills, from which measurement data were obtained, were collected from 12 different populations. The area of these bodies of water ranged from 1.0 to several thousands of acres, however the majority were ponds less than 3 acres in area (Table 14). The size of the individual bluegills in the samples ranged from 14 to 235 millimeters in total length (Table 15).

Table 14. Bluegill population data.

Pond	Pond area acres	Stocking rate per acre	Date stocked	Date collected	Total length Min. Mm.	Total length Max. Mm.	Total N
E-6	1.0	1,000	11-30-48	10-18-51	18	208	748
E-7	1.0	1,000	11-30-48	11-2-51	21	213	713
E-8	1.0	1,000	11-30-48	9-18-51	22	215	385
FP-4	1.4	1,000	2-2-51	10-23-52	32	156	243
S-4	1.3	*	1-3-49	10-10-50	30	178	60
S-8	10.7	20**	1-1-49	11-7-50	75	160	95
S-11	2.6	1,000	11-30-48	11-15-50	14	235	459
S-12	2.2	1,500	11-30-48	11-20-50	24	195	689
S-14	12.4	1,500	12-14-48	11-8-50	20	226	1,503
FP-1	1.6	10**	4-21-51	1-12-52	29	212	119
Kings pond	3.0	unknown		2-15-51	59	215	268
Lake Martin		unknown		7-26-51	24	215	253

* No bluegills were included in the original stocking of this pond.
** Adult bluegills were used to stock these ponds.

It will be noted that the total number of individuals in each bluegill population sample is somewhat larger than the number of individuals used to compute the regression equations. This reduction in numbers was made to permit easier computations of sums of squares and cross products. The selection of individuals to be included in these computed samples was made as follows. The measurement data were arranged in numerical order, based

Table 15. Frequencies by total length inch-groups of bluegills from each population.

Pond	In. Mm.	1 13-38	2 39-63	3 64-89	4 90-114	5 115-139	6 140-165	7 166-190	8 191-216	9 217-242	Total N
E-6		70	108	125	97	158	173	12	5		748
E-7		27	92	109	42	164	208	59	12		713
E-8		134	68	-	16	51	55	53	8		385
FP-4		51	86	6	6	64	30	-	-	-	243
S-4		3	26	6	-	19	6	-	-	-	60
S-8		-	-	1	36	50	8	-	-	-	95
S-11		169	84	118	26	12	30	18	-	2	459
S-12		265	183	150	12	3	35	39	2	-	689
S-14		910	312	147	62	6	3	40	22	1	1503
FP-1		26	57	27	-	-	1	3	5	-	119
Kings pond		-	6	109	117	16	8	4	8	-	268
Lake Martin		99	63	46	14	7	20	2	2	-	253

upon total length, for each population of bluegills. At least one individual for each millimeter of total length included in the population sample was selected for the computed sample. In those cases where there were several individuals with the same total length in a population, two or more individuals which had the smallest and largest maximum depth of body measurements were selected for computing. This type of selection was used so that maximum variations in the regression equations might be estimated.

In computing the regression equations, the sums of squares and cross products were determined from both actual and logarithmic values of measurement data. The linear regression coefficients, with their respective standard deviations and correlation coefficients, determined from actual and logarithmic values of measurements for each pond population of bluegills are given in Table 16.

Tests were made, using analysis of covariance, for homogeneity of bluegill populations regression coefficients between total length and maximum depth of body as determined from actual and logarithmic values of measurements. With actual values of measurements the following analysis was obtained:

	D.F.	S.S.	M.S.	F
Total	1175	26,004.1		
Populations	1164	25,137.3	21.6	
Difference	11	866.8	78.8	3.65

With logarithmic values of measurements the following analysis was obtained:

Table 16. Regression coefficients, standard deviations and correlation coefficients for relationship of maximum depth of body to total length of bluegills in each population. Determined from actual and logarithmic values of measurement data.

Pond	N	Actual values b	s	r	Logarithmic values b	s	r
S-11	117	.3988	2.64	.9928	1.2127	.0264	.9967
S-12	107	.3816	1.49	.9975	1.2424	.0145	.9990
S-8	41	.4120	1.60	.9780	1.2174	.0529	.9793
S-4	40	.4263	2.66	.9938	1.2834	.0735	.9975
S-14	135	.3763	7.76	.9471	1.2233	.0118	.9993
F.P.4	71	.3877	1.61	.9954	1.2367	.0173	.9982
E-6	158	.3853	1.28	.9975	1.2459	.0263	.9964
E-7	198	.3834	8.52	.8974	1.2045	.0217	.9963
E-8	111	.4136	2.26	.9957	1.2262	.0017	.9990
F.P.1	51	.4208	1.71	.9975	1.2850	.0728	.9969
King	79	.4390	1.71	.9957	1.2845	.0141	.9974
Martin	80	.3869	1.94	.9949	1.2103	.0332	.9945

	D.F.	S.S.	M.S.	F
Total	1175	.597398		
Populations	1164	.560608	.000482	
Difference	11	.036790	.003345	6.94

At a P = .01 the tabular F is 2.26 with $N_1 = 11$ and $N_2 = 1164$ degrees of freedom. Since the calculated F's in these analyses were highly significant, the regression coefficients of the pond populations of bluegills were heterogeneous.

Since the primary purpose of this phase of the investigation was to provide equations for estimating maximum depth of body from total length of bluegills, the heterogeneity of populations regression coefficients was disregarded and the measurement data from all populations were combined. Such a procedure was necessary to give greater range of total length for prediction equations and also to provide sufficient individuals so that reliable estimates of variations would be obtained.

After combining the measurement data of all bluegill populations, the data were arranged in numerical order based upon total length. From these combined data the mean maximum depth of body for each 10 millimeter and each inch-group interval of total length was determined (Table 17).

The combined data estimating equation, with its standard deviation and correlation coefficient, determined from actual values of measurements was as follows:

$$D = -6.07 + 0.3990\ L, \quad s = 4.01, \quad r = .9812$$

The combined data estimating equation, and accompanying statistics, determined from logarithmic values of measurements was as follows:

$$\log D = -0.9572 + 1.2352 \log L, \quad s = .0028, \quad r = .9969$$

Since the combined largemouth bass data had to be divided into 100 millimeter total length intervals to give reliable estimating equations, the combined bluegill data was also divided into similar intervals. The regression equations, with accompanying standard deviations and correlation coefficients, as determined from actual values of measurements of bluegills were as follows:

Table 17. Mean maximum depths of body of bluegills for given total length intervals.

Total length In.	Mm.	N	Mean maximum depth of body In.	Mm.
1	15	4	0.15	3.9
	25	58	0.28	7.1
	25	141	0.29	7.4
	35	87	0.36	9.1
	45	79	0.49	12.4
2	51	195	0.55	14.1
	55	76	0.62	15.7
	65	75	0.77	19.6
	75	73	0.93	23.6
3	77	189	0.94	23.7
	85	74	1.10	28.1
	95	63	1.23	31.3
4	102	146	1.35	34.4
	105	55	1.40	35.6
	115	69	1.57	40.1
	125	69	1.73	44.0
5	127	180	1.75	44.6
	135	70	1.81	46.2
	145	66	2.05	52.2
6	153	176	2.14	54.6
	155	66	2.18	55.5
	165	63	2.38	60.7
	175	45	2.53	64.6
7	178	108	2.56	65.4
	185	43	2.70	68.9
	195	17	2.89	73.7
8	203	50	3.06	78.1
	205	25	3.25	82.9
	215	9	3.31	84.4
	225	2	3.59	91.5
9	229	3	3.45	87.9

Less 100 mm. $D = -2.79 + 0.3441\ L$, $s = 2.61$, $r = .9455$

100-199 mm. $D = -9.14 + 0.4200\ L$, $s = 4.90$, $r = .9120$

200-299 mm. $D = -47.52 + 0.6092\ L$, $s = 2.88$, $r = .8521$

Analysis of covariance was used to test the homogeneity of the 100 millimeter total length interval groups regression coefficients between total length and maximum depth of body of bluegills. With actual values of measurements the following analysis was obtained:

	D.F.	S.S.	M.S.	F
Total	1184	22,742.8		
Groups	1182	21,219.3	17.95	
Difference	2	1,523.5	761.80	42.444

At a $P = .01$ the tabular F is 4.62 with $N_1 = 2$ and $N_2 = 1182$ degrees of freedom. These analyses indicate heterogeneous regression coefficients for the three total length groups of bluegills.

The ability of each of these calculated regression equations to estimate the maximum depth of body of bluegills was tested by use of the following equation:

$$(\hat{D} / \bar{D} \times 100) - 100 = \text{percent difference.}$$

The mean maximum depth of body of bluegills used in this equation were taken from Table 17. The calculated differences, as percentages, are given in Table 18. In all three cases at the lower limits of total length range for equations the estimated values are in greater error, percentage wise, from the means than they are for the remainder of the range. From a practical point of view, there were small differences in the abilities of the three sets of equations to predict the maximum depth of body of bluegills.

Table 18. Differences, as percentages of means, between mean maximum depths of body for bluegills and values estimated from linear regressions.

Total length In.	Inch-group mean Mm.	N	Mean depth of body Mm.	Deviations of estimated depth of body as percentages of means: Actual value, Total range	Actual value, 100 mm. range	Logarithmic value, Total range
1	31.8	141	7.4	-10.6	10.8	6.7
2	49.1	195	14.1	-4.3	0.0	-3.5
3	74.6	189	23.7	0.0	-3.4	-4.2
4	101.8	146	34.4	0.4	-2.3	-3.2
5	126.6	180	44.6	-0.9	-1.1	-2.2
6	152.3	176	54.6	-0.7	0.4	0.4
7	176.2	108	65.4	-1.8	-0.8	0.5
8	201.4	50	78.1	-4.9	-3.7	-0.9

Redear sunfish

The populations from which measurements of redear sunfish could be obtained were limited to three (Table 19). The reason for such meager data on this species arose from the difficulty in separating the small pure redears from the bluegill x redear hybrids which were present in many of the populations. Thus only those populations were used where positive identification was possible. Due to the small numbers of this species present in most pond populations, their importance in the application of the results of this investigation is limited.

Table 19. Redear sunfish population data.

Pond	Pond area acres	Stocking rate per acre	Date stocked	Date collected	Total length Min. Mm.	Max. Mm.	Total N
S-14	12.4	500	1-3-51	9-23-52	75	155	120
S-14	12.4	500	12-14-48	11-8-50	170	220	64
Lay Lake	. . . unknown			8-5-50	50	210	23

With this species some selectivity of the individuals used for computations was exercised to give maximum variations as well as more equalized numbers of individuals over the range of total length available for analysis. The range in total length of redear sunfish was from 50 to 220 millimeters (Table 20).

The regression coefficients for relationship of maximum depth of body to total length of redear sunfish were determined from actual and logarithmic values of measurement data for each population (Table 21). The homogeneity of the regression coefficients for populations of redear

Table 20. Frequencies by total length inch-groups of redear sunfish from each population.

Pond	In. Mm.	2 39-63	3 64-89	4 90-114	5 115-139	6 140-165	7 166-190	8 191-216	9 217-242	N
S-14							18	45	1	64
S-14			8	46	64	2				120
Lay Lake		3	3	13	1	2			1	23

Table 21. Regression coefficients, standard deviations and correlation coefficients for relationship of maximum depth of body to total length of redear sunfish in each population. Determined from actual and logarithmic values of measurement data.

Pond	N	Actual values			Logarithmic values		
		b	s	r	b	s	r
S-14	41	.3859	4.37	.8792	1.0248	.0185	.9621
S-14	73	.3691	1.97	.9757	1.0524	.0225	.9918
Lay	23	.3683	1.96	.9879	1.0768	.0782	.9864

sunfish was tested by analyses of covariance using both actual and logarithmic values of measurements. With actual values of measurements the following analysis was obtained:

	D.F.	S.S.	M.S.	F
Total	133	714.26		
Populations	131	712.26	5.44	
Difference	2	2.00	1.00	0.18

With logarithmic values of measurements the following analysis was obtained:

	D.F.	S.S.	M.S.	F
Total	133	.061271		
Populations	131	.060830	.000464	
Difference	2	.000441	.000220	0.47

In each of these analyses the mean squares of deviation within populations were greater than the mean squares of deviations between populations, thus one would assume that the redear sunfish populations regression coefficients were homogeneous. Apparently when the individuals were selected from each population for computations, the data obtained maximumized the within populations variation and tended to minimize the between populations variation.

The measurement data of all redear sunfish populations were combined and arranged in numerical order based upon total length. From these combined data the mean maximum depth of body for each 10 millimeter and each inch-group interval of total length was determined (Table 22).

The combined data estimating equation, with its standard deviation and correlation coefficient, determined from actual values of measurements was as follows:

$$D = -0.93 + 0.3371\ L, \quad s = 2.51, \quad r = .9874$$

The combined data estimating equation, with accompanying statistics, determined from logarithmic values of measurements was as follows:

$$\log D = -0.5557 + 1.0344 \log L, \quad s = .0636, \quad r = .9919$$

Estimating equations for 100 millimeter intervals of total length for redear sunfish were also determined. The linear regression equations with their accompanying standard deviations and correlation coefficients determined from actual values of measurements were as follows:

Less 100 mm. $D = 0.71 + 0.3104\ L, \quad s = 1.27, \quad r = .9623$

100-199 mm. $D = 2.04 + 0.3173\ L, \quad s = 2.60, \quad r = .9643$

200-299 mm. $D = -45.51 + 0.5523\ L, \quad s = 3.00, \quad r = .6325$

Analysis of covariance was used to test the homogeneity of the regression coefficients of 100 millimeter total length interval groups of redear sunfish. Using actual values of measurements the following analysis was obtained:

Table 22. Mean maximum depths of body of redear sunfish for given total length intervals.

Total length In.	Total length Mm.	N	Mean maximum depth of body In.	Mean maximum depth of body Mm.
	45	1	0.67	17.0
2	51	3	0.69	17.7
	55	1	0.71	18.0
	65	3	0.71	18.0
	75	7	0.97	24.8
3	77	13	1.01	25.8
	85	5	1.15	29.3
	95	21	1.19	30.4
4	102	45	1.31	33.2
	105	12	1.39	35.5
	115	20	1.51	38.5
	125	12	1.68	42.9
5	127	27	1.67	42.8
	135	8	1.84	46.9
	145	3	1.88	48.0
6	153	6	1.87	47.5
	155	1	2.00	51.0
	165	1	2.08	53.0
	175	10	2.27	57.9
7	178	18	2.30	58.4
	185	7	2.35	60.0
	195	5	2.56	65.4
8	203	25	2.70	68.7
	205	16	2.78	70.5
	215	4	2.85	72.8

	D.F.	S.S.	M.S.	F
Total	133	840.88		
Groups	131	782.13	5.88	
Difference	2	22.75	11.38	1.94

At a P = .01 the tabular F is 4.78 with $N_1 = 2$ and $N_2 = 131$ degrees of freedom. This analysis indicates that the regression coefficients between 100 millimeter total length interval groups were homogeneous.

The ability of each of the calculated prediction equations to estimate the maximum depth of body of redears was determined by the following equation:

$$(\hat{D}/\bar{D} \times 100) - 100 = \text{percent difference.}$$

The mean maximum depth of body used in the above equation was taken from Table 22. The differences, as percentages, are given in Table 23. The differences in values of estimated and mean maximum depths of body are about as great using one prediction equation as another. For practical

Table 23. Differences, as percentages of means, between average maximum depths of body for redear sunfish and values estimated from linear regressions.

Total length In.	Total length Inch-group mean Mm.	N	Mean depth of body Mm.	Deviations of estimated depth of body as percentages of means: Actual value Total range	Actual value 100 mm. range	Logarithmic value Total value
2	56.7	3	17.7	2.8	3.4	2.3
3	77.5	13	25.8	-2.3	-1.6	-2.7
4	102.3	45	33.2	1.2	3.9	0.6
5	125.2	27	42.8	-3.5	-2.3	-4.0
6	144.3	6	47.5	0.4	0.6	0.2
7	180.2	18	58.4	2.4	1.4	3.8
8	206.0	25	68.7	-0.3	-0.6	0.1

purposes, the single estimating equation determined from actual values of measurements gave satisfactory estimates of maximum depth of body.

Green sunfish

The green sunfish, from which measurement data were obtained, were collected from 6 different pond populations and 4 different lake populations. The area of the ponds ranged from 0.25 to 12.7 acres whereas the areas of the lakes were several thousands of acres (Table 24). The size of the green sunfish included in these samples ranged from 16 to 181 millimeters in total length (Table 25).

Table 24. Green sunfish population data.

Pond	Pond area acres	Date stocked	Date collected	Total length Min. Mm.	Max. Mm.	Total N
F-3	0.25	1-2-51*	6-9-52	38	107	24
F-12	0.25	1-2-51*	6-4-52	74	181	9
E-8	1.00	11-30-48*	9-18-51	29	134	19
S-14	12.4	1-3-51*	9-23-52**	60	94	14
S-14	12.4	1-3-51	11-16-52	66	155	42
S-14	12.4	1-3-51	11-17-52	35	155	161
Lake Martin	unknown		7-26-51**	16	139	222
Lake Martin	unknown		7-27-51**	14	84	110
Lake Jordan	unknown		7-24-52**	26	101	70
Lake Mitchell	unknown		8-10-50**	38	127	44

* Bluegill stocking date, supposedly no green sunfish stocked.
** Samples taken by rotenone poisoning.

Table 25. Frequencies by total length inch-groups of green sunfish from each population.

Pond	In. Mm.	1 13-38	2 39-63	3 64-89	4 90-114	5 115-139	6 140-165	7 166-190	Total N
F-3		1	21	1	1	-	-	-	24
F-12		-	-	3	3	1	1	1	9
E-8		5	4	8	-	2	-	-	19
S-14		-	1	12	1	-	-	-	14
S-14		-	-	3	20	9	10	-	42
S-14		5	53	43	38	12	10	-	161
Lake Martin		160	43	16	6	2	-	-	227
Lake Martin		88	14	8	-	-	-	-	110
Lake Jordan		30	23	16	1	-	-	-	70
Lake Mitchell		1	15	21	5	2	-	-	44

There was some selectivity of those individuals from some populations which would be included in the samples for computations. This was done to obtain a more even distribution of the numbers of individuals over the entire range of total length and to obtain maximum variations in the body measurements.

The regression coefficients for the relationship of maximum depth of body to total length of green sunfish were determined from actual and logarithmic values of measurement data for each population (Table 26).

Table 26. Regression coefficients, standard deviations and correlation coefficients for relationship of maximum depth of body to total length of green sunfish in each population. Determined from actual and logarithmic values of measurement data.

Pond	N	Actual values			Logarithmic values		
		b	s	r	b	s	r
F-3	14	.4221	1.14	.9899	1.2375	.0232	.9889
F-12	9	.3804	3.71	.9721	1.0801	.0380	.9716
E-8	16	.3424	0.96	.9960	1.1121	.0140	.9980
S-14	12	.3422	1.44	.9859	1.0688	.0192	.9592
S-14	42	.4084	2.15	.9762	1.2503	.0228	.9813
S-14	118	.3495	2.97	.9574	1.0141	.0643	.9121
Martin	37	.3238	1.38	.9714	1.1778	.0260	.9945
Martin	36	.3357	1.22	.9940	1.1049	.0572	.9975
Jordan	35	.3166	1.13	.9853	1.1372	.0312	.9874
Mitchell	44	.3499	1.57	.9710	1.1303	.0303	.9680

The homogeneity of regression coefficients for relationship of total length and maximum depth of body for each population of green sunfish was tested by analyses of covariance using actual and logarithmic values of measurements. With actual values of measurements the following analysis was obtained:

	D.F.	S.S.	M.S.	F
Total	351	962.64		
Populations	341	816.69	2.39	
Difference	10	45.95	4.96	2.08

With logarithmic values of measurements the following analysis was obtained:

	D.F.	S.S.	M.S.	F
Total	351	.664512		
Populations	341	.621601	.001823	
Difference	10	.042911	.004291	2.35

At a $P = .01$ the tabular F is 2.39 with $N_1 = 10$ and $N_2 = 341$ degrees of freedom. From these analyses it would be concluded that these populations regression coefficients were homogeneous. However the calculated F for the logarithmic values is so near the tabular F that one suspects that these populations regression coefficients are approaching heterogeneity.

The measurement data of all green sunfish populations were combined and arranged in numerical order based upon total length. From these combined data the average maximum depth of body for each 10 millimeter and each inch-group interval of total length was determined (Table 27).

The combined data estimating equation, with its standard deviation and correlation coefficient, determined from actual values of measurements of green sunfish was as follows:

$$D = -3.67 + 0.3624\ L, \quad s = 3.31, \quad r = .9864$$

The combined data estimating equation, with accompanying statistics, determined from logarithmic values of measurements of green sunfish were as follows:

$$\log D = -0.7677 + 1.1351 \log L, \quad s = .0452, \quad r = .9803$$

Estimating equations for 100 millimeter intervals of total length for green sunfish were also determined. The regression equations, respective

Table 27. Mean maximum depths of body of green sunfish for given total length intervals.

Total length In.	Total length Mm.	N	Mean maximum depth of body In.	Mean maximum depth of body Mm.
	15	4	0.13	3.3
	25	19	0.29	7.3
1	25	61	0.33	8.3
	35	43	0.40	10.1
	45	36	0.50	12.8
2	51	109	0.60	15.1
	55	57	0.66	16.8
	65	57	0.77	19.7
	75	39	0.91	23.2
3	77	106	0.89	22.5
	85	33	1.07	27.4
	95	22	1.20	30.5
4	102	56	1.25	31.8
	105	19	1.38	35.2
	115	6	1.47	37.6
	125	9	1.65	42.2
5	127	19	1.71	43.6
	135	8	1.88	47.9
	145	6	2.00	51.0
6	153	11	2.04	51.9
	155	3	2.07	52.8
	165	1	2.24	57.0
	175	0	-	-
7	178	1	2.59	66.0
	185	1	2.59	66.0

standard deviations and correlation coefficients, determined from actual values of measurements of green sunfish were as follows:

Less 100 mm. $D = -2.09 + 0.3337\ L$, $s = 1.41$, $r = .9785$

100–199 mm. $D = -9.42 + 0.4148\ L$, $s = 2.65$, $r = .9475$

The homogeneity of regression coefficients for the 100 millimeter total length interval groups of green sunfish was tested by analysis of covariance. Using actual values of measurements the following analysis was obtained:

	D.F.	S.S.	M.S.	F
Total	360	1125.39		
Groups	359	1009.09	2.81	
Difference	1	116.30	116.30	41.39

At a $P = .01$ the tabular F is 6.72 with $N_1 = 1$ and $N_2 = 359$ degrees of freedom. This analysis indicates that the regression coefficients for the two 100 millimeter interval groups of green sunfish were heterogeneous.

The ability of each of these calculated equations to estimate the maximum depth of body of green sunfish was tested using the following equation:

$$(\hat{D}/\bar{D} \times 100) - 100 = \text{percent difference.}$$

The mean maximum depth of body used in this equation was taken from Table 27. The differences, as percentages, are given in Table 28. With this species the regression equations determined for 100 millimeter intervals of actual values of measurements gave better estimates of maximum depth of body of green sunfish than did either of the other equations. However, for practical application the total range actual value equations would give sufficiently accurate estimates.

Golden shiners

The measurement data on the golden shiners were obtained from 6 different pond populations (Table 29). Five of these populations were from ponds in which this species was being grown as bait minnows. The

Table 28. Differences, as percentages of means, between mean maximum depth of body for green sunfish and values estimated from linear regressions.

Total length In.	Total length Inch-group mean Mm.	N	Mean depth of body Mm.	Deviations of estimated depths of body as percentages of means: Actual value, Total range	Actual value, 100 mm. range	Logarithmic value, Total range
1	31.8	61	8.3	-4.8	2.4	4.8
2	52.5	109	15.1	2.0	2.0	1.3
3	73.7	106	22.5	2.2	0.0	0.0
4	99.3	56	31.8	1.6	-2.2	-0.6
5	127.6	19	43.6	-2.3	-0.2	-3.7
6	149.0	11	51.9	-3.1	1.0	-3.7
7	181.0	1	66.0	-6.2	-0.5	-5.5

Table 29. Golden shiner minnow population data.

Pond	Pond area acres	Stocking rate per acre	Date stocked	Date collected	Total length Min. Mm.	Total length Max. Mm.	Total N
F-14	0.25	1,200	2-23-52	12-5-52	49	177	172
F-10	0.25	2,400	4-30-51	2-14-52	71	155	120
F-22	0.25	2,400	4-30-51	2-7-52	50	107	207
F-23	0.25	4,800	4-30-51	2-7-52	54	145	173
S-25	1.00	30,000	2-15-52	4-17-52	48	84	122
S-6	25.5	unknown		10-18-55	81	215	220

area of these ponds varied from 0.25 to 1.0 acre. The size range of the minnows in these samples was from 48 to 177 millimeters in total length (Table 30). The sixth population of golden shiner was from a 25.5 acre pond, in which the golden shiners had established themselves along with a bluegill-bass combination. The size distribution of these minnows was from 81 to 215 millimeters in total length.

In computing the linear relationship between maximum depth of body and total length of golden shiners, the sums of squares and cross products were determined from actual and from logarithmic values of measurements (Table 31).

The homogeneity of regression coefficients for relationship of maximum depth of body to total length for each population of golden shiners

Table 30. Frequencies by total length inch-groups of golden shiner minnows from each pond population.

Pond	In. / Mm.	2 / 39-63	3 / 64-89	4 / 90-114	5 / 115-139	6 / 140-165	7 / 166-190	8 / 191-216	Total / N
F-14		8	149	13	-	1	1	-	172
F-10		-	55	63	-	2	-	-	120
F-22		7	155	45	-	-	-	-	207
F-23		9	155	7	1	1	-	-	173
S-25		73	49	-	-	-	-	-	122
S-6		-	2	21	119	44	25	9	220

Table 31. Regression coefficients, standard deviations and correlation coefficients for relationship of maximum depth of body to total length of golden shiners in each pond population. Determined from actual and logarithmic values of measurement data.

Pond	N	Actual values			Logarithmic values		
		b	s	r	b	s	r
F-14	68	.2680	1.23	.9700	1.1737	.0328	.9509
F-10	47	.3098	1.17	.9706	1.3895	.0261	.9967
F-22	78	.2207	1.12	.9327	1.0743	.0333	.9225
F-23	68	.2743	0.71	.9860	1.3186	.0178	.9848
S-25	54	.2502	1.22	.8837	1.1891	.0394	.8832
S-6	137	.2746	1.65	.9772	1.2527	.0239	.9752

was tested by analysis of covariance using actual and logarithmic values of measurements. With actual values of measurement data the following analysis was obtained:

	D.F.	S.S.	M.S.	F
Total	445	775.92		
Populations	440	725.73	1.65	
Difference	5	50.19	10.04	6.08

With logarithmic values of measurements the following analysis was obtained:

	D.F.	S.S.	M.S.	F
Total	445	.379238		
Populations	440	.359446	.000819	
Difference	5	.019792	.003958	4.83

At a P = .01 the tabular F is 3.05 with $N_1 = 5$ and $N_2 = 440$ degrees of freedom. Thus the regression coefficients for pond populations of golden shiners were heterogeneous.

Since the purpose of this investigation was to determine prediction equations for maximum depth of body to total length relationships, the heterogeneous nature of the regression coefficients was disregarded and all measurement data of golden shiner populations were combined. These combined data were then arranged in numerical order, starting with the smallest and proceeding to the larges, based upon their total length. The individuals were then divided into 10 millimeter and inch-group intervals of total length, and the mean maximum depth of body for each interval was determined (Table 32).

The combined data estimating equation, with its standard deviation and correlation coefficient, determined from actual values of measurements was as follows:

$$D = -4.0 + 0.2501\ L, \quad s = 1.50, \quad r = .9863$$

The combined data estimating equation, and accompanying statistics, determined from logarithmic values of golden shiner measurements was as follows:

$$\log D = -0.7696 + 1.0406 \log L, \quad s = 0.0619, \quad r = .9333$$

Estimating equations for 100 millimeter total length interval groups of golden shiners were also determined. The regression equations with their respective standard deviations and correlation coefficients as determined from actual values of measurements were as follows:

Less 100 mm. $D = -0.69 + 0.2074\ L, \quad s = 1.16, \quad r = .9121$

100-199 mm. $D = -7.35 + 0.2726\ L, \quad s = 1.76, \quad r = .9700$

200-299 mm. $D = -42.54 + 0.4539\ L, \quad s = 1.98, \quad r = .9375$

Analysis of covariance test was used to determine the homogeneity of regression coefficients for 100 millimeter total length interval groups

Table 32. Mean maximum depths of body of golden shiners for given total length intervals.

Total length In.	Total length Mm.	N	Mean maximum depth of body In.	Mean maximum depth of body Mm.
	45	6	0.38	9.8
2	51	47	0.45	11.5
	55	29	0.47	11.9
	65	70	0.51	13.0
	75	74	0.57	14.6
3	77	203	0.59	15.0
	85	79	0.66	16.8
	95	47	0.75	19.1
4	102	78	0.78	19.9
	105	17	0.83	21.2
	115	20	0.95	24.3
	125	23	1.04	26.6
5	127	57	1.07	27.1
	135	22	1.20	30.6
	145	16	1.29	33.0
6	153	35	1.35	34.4
	155	11	1.50	38.0
	165	12	1.51	38.1
	175	11	1.58	40.1
7	178	24	1.59	40.2
	185	7	1.65	42.1
	195	6	1.83	46.7
8	203	8	1.91	48.4
	205	1	1.96	50.0
	215	1	1.96	50.0

of golden shiners. Using the actual values of measurements the following analysis was obtained:

	D.F.	S.S.	M.S.	F
Total	448	985.99		
Groups	446	847.58	1.90	
Difference	2	138.41	69.21	36.43

At a $P = .01$ the tabular F is 4.66 with $N_1 = 2$ and $N_2 = 446$ degrees of freedom. This analysis indicates that these regression coefficients for 100 millimeter total length interval groups of golden shiners are heterogeneous.

The ability of each of these calculated equations to estimate the maximum depth of body of golden shiners was tested by use of the following equation:

$$(\hat{D} / \bar{D} \times 100) - 100 = \text{percent difference.}$$

The mean maximum depths of body used in this equation were taken from Table 32. The differences, as percentages, are given in Table 33. The differences obtained with each of the equations were greater for the

Table 33. Differences, as percentages of means, between mean maximum depth of body for golden shiners and values estimated from linear regressions.

Total length In.	Total length Inch-group mean Mm.	N	Mean depth of body Mm.	Deviations of estimated depths of body as percentages of means: Actual value, Total range	Actual value, 100 mm. range	Logarithmic value, Total range
2	55.9	47	11.5	-13.0	-5.2	-2.6
3	76.3	203	15.0	0.7	0.7	2.6
4	92.8	78	19.9	-3.5	-6.5	-4.5
5	126.8	57	27.1	2.2	0.4	-3.4
6	151.5	35	34.4	-1.5	-1.5	-9.1
7	176.7	24	40.2	0.0	1.5	-7.7
8	200.5	8	48.4	-4.8	0.2	-2.6

golden shiners than had been encountered in any of the previously discussed species. It would appear that the maximum depth of body of golden shiners could be estimated more accurately by the 100 millimeter total length interval groups equations than by either of the other types.

Goldfish

The goldfish, from which measurement data were obtained, were collected from 5 different commercial minnow pond populations (Table 34). The area of these ponds varied from 0.05 to 0.63 acre. The sise of the goldfish ranged from 35 to 130 millimeters in total length (Table 35).

These were all randomly selected samples of goldfish from each population, and thus many different degrees of fan-tailed individuals were present and were included in the measurement data. Some selectivity was exercised in those data chosen for computations. However, this selectivity was again directed in trying to have approximately equal numbers within each inch-group, and to obtain the maximum variation that was present in the samples.

The regression coefficients for the relationship of maximum depth of body to total length of goldfish were determined from actual and logarithmic values of measurement data for each pond population (Table 36).

The homogeneity of regression coefficients for relationship between maximum depth of body and total length for each pond population of goldfish was tested by analyses of covariance using actual and logarithmic values of measurements. With actual values of measurements the following analysis was obtained:

Table 34. Goldfish population data.

Pond	Pond area acres	Date stocked	Date collected	Total length Min. Mm.	Total length Max. Mm.	Total N
H-7	0.05	5-22-52	9-3-52	68	115	114
B-4	0.08	5-14-52	7-28-52	90	121	68
M-2	0.63	4-4-50	3-22-51	60	91	177
H-1	0.05			35	99	156
B-4	0.08	5-14-52	7-31-52	89	122	35
H-5	0.05			44	110	139
H-2	0.05	5-7-52	3-31-53	55	130	152

Table 35. Frequencies by total length inch-groups of goldfish from each pond population.

Pond	In. Mm.	13-38	39-63	64-89	90-114	115-139	Total N
H-7		-	37	69	6	2	114
B-4		-	-	1	50	17	68
M-2		-	3	172	2	-	177
H-1		1	137	17	1	-	156
B-4		-	-	1	32	2	35
H-5		-	29	96	13	1	139
H-2		-	7	132	11	2	152

Table 36. Regression coefficients, standard deviations and correlation coefficients for relationship of maximum depth of body to total length of goldfish in each pond population. Determined from actual and logarithmic values of measurement data.

Pond	N	Actual values b	s	r	Logarithmic values b	s	r
H-7	31	.3474	1.54	.9444	1.2477	.0336	.9257
B-4	55	.2996	1.43	.8391	0.7186	.0306	.6550
M-2	45	.4119	1.43	.9165	1.0128	.0264	.8694
H-1	34	.2830	1.94	.8648	0.9344	.0760	.7463
B-4	44	.2355	1.99	.7280	0.8597	.0565	.8677
H-5	108	.3061	2.08	.8994	1.1697	.0460	.9090
H-2	36	.2853	1.65	.7739	1.0907	.0347	.7321

	D.F.	S.S.	M.S.	F
Total	345	1,294.69		
Populations	339	1,105.34	3.26	
Difference	6	189.35	31.56	9.86

With logarithmic values of measurements the following analysis was obtained:

	D.F.	S.S.	M.S.	F
Total	345	.599014		
Populations	339	.571498	.001686	
Difference	6	.027516	.004586	2.72

At a $P = .01$ the tabular F is 2.86 with $N_1 = 6$ and $N_2 = 339$ degrees of freedom. Thus with actual values of measurements the regression coefficients were heterogeneous between the pond populations of goldfish while with logarithmic values the regression coefficients were homogeneous.

The individual goldfish from all pond populations were combined and arranged in numerical order based upon their total length. The mean maximum depth of body for each 10 millimeter and for each inch-group interval of total length was determined (Table 37).

Table 37. Mean maximum depth of body of goldfish for given total length intervals.

Total length In.	Total length Mm.	N	Mean maximum depth of body In.	Mean maximum depth of body Mm.
1	25	1	0.31	8.0
	35	1	0.33	8.5
	45	19	0.45	11.5
2	51	71	0.50	12.7
	55	34	0.52	13.3
	65	68	0.74	18.8
	75	72	0.92	23.4
3	77	158	0.98	25.0
	85	42	1.02	26.0
	95	40	1.07	27.3
4	102	94	1.11	28.3
	105	34	1.17	29.9
	115	33	1.22	31.0
	125	10	1.36	34.6
5	127	29	1.28	32.6

From these combined data estimating equations of the relationship of maximum depth of body to total length were determined using actual and logarithmic values of measurements. The combined data estimating equation, with its standard deviation and correlation coefficient, determined from actual values of measurements of goldfish was as follows:

$$D = -0.56 + 0.2875\,L, \quad s = 3.42, \quad r = .8637$$

The combined data estimating equation, with accompanying estimators, determined from logarithmic values of goldfish measurements was as follows:

$$\log D = -0.7955 + 1.1240 \log L, \quad s = .0692, \quad r = .8752$$

Estimating equations for 100 millimeter intervals of total length for goldfish were also determined. The regression equations with their accompanying standard deviations and correlation coefficients as determined from actual values of measurements were as follows:

Less 100 mm. $D = -3.96 + 0.3372\,L, \quad s = 3.67, \quad r = .7855$

100-199 mm. $D = 10.42 + 0.1822\,L, \quad s = 1.80, \quad r = .5815$

The homogeneity of the regression coefficients for the 100 millimeter total length interval groups was tested using analysis of covariance. With actual values of measurements the following analysis was obtained:

	D.F.	S.S.	M.S.	F
Total	350	3,965.66		
Groups	349	3,872.27	11.10	
Difference	1	93.39	93.39	8.41

At a $P = .01$ the tabular F is 6.71 with $N_1 = 1$ and $N_2 = 349$ degrees of freedom. From this analysis it is concluded that the regression coefficients for the 100 millimeter total length intervals for goldfish are heterogeneous.

The ability of each of these calculated prediction equations to estimate the maximum depth of body of goldfish was tested by use of the following equation:

$$(\hat{D} / \bar{D} \times 100) - 100 = \text{percent difference.}$$

The mean maximum depth of body of goldfish used in this equation were taken from Table 37. The differences in estimated and mean maximum depth of body of goldfish were more variable than for any other species included in this study (Table 38). However, when it is considered that no attempt was made to obtain specimens with uniformly shaped tails, the variations in estimated and mean values are not excessive. Due to the scattered type of variation exhibited in Table 38, it is difficult to select the equation which would produce the best estimates of maximum depth of body of goldfish.

Table 38. Differences, as percentages of means, between mean maximum depths of body for goldfish and values estimated from linear regressions.

Total length In.	Total length Inch-group mean Mm.	N	Mean depth of body Mm.	Deviations of estimated depth of body as percentages of means: Actual value, Total range	Actual value, 100 mm. range	Logarithmic value, Total range
1	35.0	1	8.0	18.7	-2.5	8.8
2	55.4	71	12.7	21.2	15.7	15.0
3	75.4	158	25.0	-15.6	-14.0	-17.2
4	101.0	94	28.3	0.7	1.8	1.1
5	119.4	29	32.6	3.7	-1.8	6.1

Sizes of Forage Fishes a Largemouth Bass Can Swallow

The second objective of this investigation was to determine the total length of selected forage fishes a largemouth bass of a given size would readily swallow. To accomplish this it was necessary to observe the manner in which a bass normally swallows a fish. The general procedure of swallowing or gulping a fish follows. The bass takes the fish into its mouth head first. In those cases where a fish is taken sidewise or tail first, the bass spits the fish out, at the same time flipping it so that it can be recaptured head first. Once the fish is head first in the grasp of the mouth of the bass, its body is rotated 90 degrees from its vertical axis and then swallowed. This position of a forage fish in the mouth of a bass ready to be swallowed is illustrated in Figure 9.

After observing the manner whereby a bass actually feeds, it was postulated that some structure located in the thoracic region of the body must limit the size of a fish that could be swallowed by an individual. After dissecting this region of the body in several bass it was determined that the cleithrum bones were the relatively non-flexible bony structures regulating the size of an object that might pass through the esophagus of the bass. To illustrate this point, top and side views of these limiting bony structures in the largemouth bass are shown in X-ray photographs in Figures 10 and 11. It will be noted that a bluegill, whose maximum depth of body equals the mouth width of the bass, is being swallowed. It is also evident from these X-rays that the horizontal capacity of the esophagus is slightly greater than the vertical capacity. Thus with fish whose maximum depth of body approaches their maximum width of body the vertical capacity of the esophagus may be a critical measurement. In this study only those species of forage fishes are considered whose maximum depth of body is much greater than their maximum width of body.

The assumption that a largemouth bass can swallow a fish whose maximum depth of body is equal to the mouth width of the bass was checked

Figure 9. Position of bluegill in mouth of bass during act of bass swallowing a bluegill or similarly shaped fish.

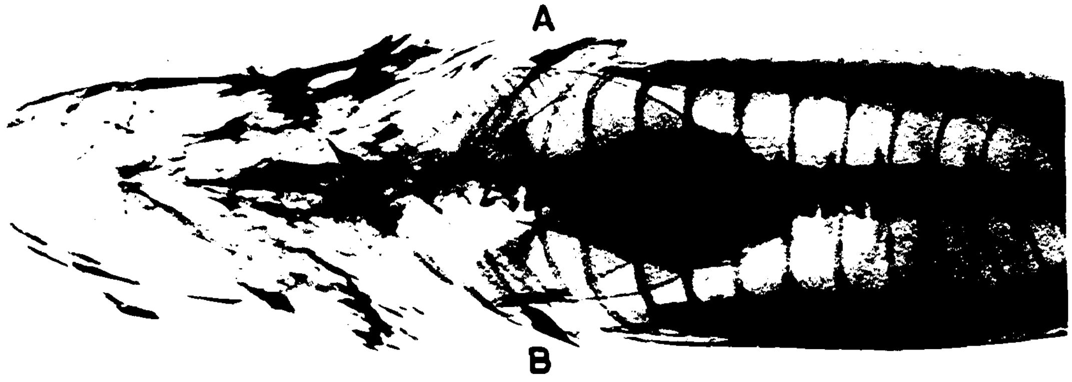

Figure 10. X-ray taken from ventral side showing bluegill, whose maximum depth of body equaled the mouth width of bass, being swallowed. Note that at points A and B the cleithrum bones regulate size of fish a bass can swallow.

Figure 11. X-ray taken from side showing position of bluegill in esophagus of bass. Note that the depth of the esophagus is not as great as the width between the cleithrum bones shown in Figure 10.

in aquaria feeding tests in the laboratory. The bass stocked in the aquaria ranged in size from 155 to 290 millimeters in total length. Their mouth width measurements ranged from 15 to 33 millimeters. The increases in mouth width measurements of these bass during the 4.5 month feeding test period in the laboratory are given in Table 39.

As stated previously, the bass were hand fed bluegills, golden shiners, or goldfish whose total length and maximum depth of body had been determined. The percentages of these forage fish offered to the bass that were eaten or rejected, according to maximum depth of body less than, equal to, or greater than the mouth width of the individual bass, are also given in Table 39. These bass were divided into two groups, those whose mouth width was less than 25 millimeters and those 25 millimeters and greater. The total number of each of the three forage species which were eaten or rejected by the two groups of bass were tabulated by millimeter groups according to differences in maximum depth of body and mouth width (Table 40). The meager goldfish and golden shiner data, resulting from the desired sizes of individuals of these species being unavailable to feed the larger bass, render this data unusable in determining the maximum sizes of these species a bass can swallow. The feeding of large numbers of smaller individuals of each species was practiced of necessity since fishes of the exact depths needed to continually tax the mouth width capacity of the bass were unavailable.

The data in Table 40 show that a number of forage fishes whose maximum depth of body was equal to or greater than the mouth width were swallowed by each bass. A selection of nine bass included in this test which either

Table 39. Percentages of forage fish offered as food to largemouth black bass in aquaria which were eaten or rejected, listed according to the relationship of the maximum depth of body of forage fish to the mouth width of bass.

Aquaria no.	Largemouth bass mouth widths		Percentage of forage fish whose					
			D < M		D = M		D > M	
	Apr.22	Sep.6	Eaten	Refused	Eaten	Refused	Eaten	Refused
1	17	20	56.5	4.3	17.4	0	18.5	3.3
2	29	30	82.6	5.8	5.8	2.3	3.5	0
3	24	25	57.1	15.4	8.8	2.2	9.9	6.6
4	22	24	72.4	6.6	13.2	0	19.7	1.3
5	32	32	85.4	7.3	3.7	0	1.2	2.4
6	30	*	82.8	3.4	6.9	0	6.9	0
7	33	33	82.7	6.2	2.5	1.2	3.7	3.7
8	33	35	83.1	4.8	3.6	2.4	4.8	0
9	28	28	70.4	12.3	4.9	1.2	4.9	6.2
10	31	31	81.5	3.5	8.2	1.2	4.7	1.2
11	27	*	65.9	4.9	12.2	2.4	7.3	7.3
12	23	26	68.5	12.3	4.1	0	12.3	2.7
13	20	24	72.5	6.3	8.8	0	11.3	1.2
14	21	23	74.4	3.7	6.1	1.2	9.8	4.9
15	22	24	76.3	6.3	8.8	2.5	3.8	2.5
16	21	*	63.2	0	5.3	0	31.6	0
17	22	25	80.8	2.5	3.8	1.3	10.3	1.3
18	27	31	83.1	1.2	4.8	0	8.4	2.4
19	30	34	81.7	6.1	4.9	1.2	1.2	4.9
20	28	32	78.2	8.0	8.0	1.1	2.3	1.1
21	29	32	86.6	2.4	2.4	0	4.9	3.7
22	15	17	54.9	5.6	14.1	1.4	19.7	4.2
23	17	21	70.1	4.5	9.0	0	14.9	1.5
24	26	28	82.4	5.4	2.7	1.4	2.7	5.4
25	23	25	70.8	5.6	6.9	1.4	15.3	0
26	20	22	77.5	2.8	9.9	0	9.9	0
27	16	18	45.7	7.1	15.7	0	25.7	5.7
28	19	20	66.2	2.8	11.3	0	19.7	0
29	26	27	82.7	1.3	8.0	2.7	2.7	1.3

* These bass died during the course of the experiment.

Table 40. Numbers of bluegills, goldfish and golden shiners eaten or rejected by mouth width size groups of bass, and divided into millimeter groups based upon differences between maximum depth of body of forage fishes and mouth width of bass.

Largemouth bass, mouth width less than 25 millimeters.	Bluegills		Goldfish		Golden shiners*	
Depth of forage fish	Eaten	Rejected	Eaten	Rejected	Eaten	Rejected
4 or more mm. less than M.W.	36	3	233	19	60	2
3 mm. less	12	4	47	4	8	0
2 mm. less	10	2	44	2	7	0
1 mm. less	11	1	33	7	1	0
Same as M.W.	49	6	42	2	5	0
1 mm. greater	94	15	22	6	1	0
2 mm. greater	30	9	4	1	0	0
3 mm. greater	8	3	2	1	0	0
4 mm. greater	3	0	2	0	0	0
5 mm. greater	1	0	0	0	0	0
Mouth width 25 millimeters and greater						
4 or more mm. less than M.W.	107	13	332	24	68	1
3 mm. less	14	1	18	4	1	0
2 mm. less	5	4	20	1	1	0
1 mm. less	16	4	29	2	0	0
Same as M.W.	19	10	14	0	0	0
1 mm. greater	20	13	5	0	0	0
2 mm. greater	19	6	0	0	0	0
3 mm. greater	12	6	0	0	0	0
4 mm. greater	5	4	0	0	0	0
5 mm. greater	0	3	0	0	0	0

*Individuals of this species whose maximum depth of body was equal to or greater than the mouth width of these bass were either limited in number or entirely unavailable at the time this experiment was in progress.

swallowed or rejected bluegills whose maximum depth of body was 4 millimeters or more greater than the mouth width of the bass are given in Table 41. It is interesting to note that the bass with the shortest total length swallowed a bluegill whose maximum depth of body was 26.6 percent greater than its mouth width, and the next longer bass swallowed a bluegill whose maximum depth of body was 29.9 percent greater than its mouth width. With increasing total length of the bass in this selected group, the maximum depth of body of bluegills greater than the mouth width which were swallowed decreased gradually to 9.1 percent for the bass with the greatest total length. These data do not indicate the maximum size of a bluegill a largemouth bass can swallow since so few large individuals were offered the bass.

The problem of determining the maximum sizes of bluegills and other forage fishes a largemouth bass of a given size can swallow is still unsolved. However, these tests did show that a largemouth bass will readily swallow a bluegill whose maximum depth of body equals the mouth width of the bass.

If it is assumed that a bass can swallow a forage fish whose maximum depth of body is equal to the mouth width of the bass, this relationship may be expressed symbolically as follows:

$$M_{bass} = D_{forage}$$

or

$$\log M_{bass} = \log D_{forage}$$

In the previous section the regressions of maximum depth of body on total length for the forage fishes were determined. This was done to

Table 41. Selected largemouth bass from aquaria feeding tests showing the numbers of bluegills eaten (E) or rejected (R), divided into millimeter groups based upon differences between maximum depth of body of bluegills and mouth width of bass, and including the maximum sizes of bluegills presented which were eaten and rejected.

Largemouth bass		Maximum depth of bluegills to mouth width of bass												Maximum sizes of bluegills			
														Eaten		Rejected	
Total length	Mouth width	Same		1		2		3		4		5		Total length	Max. depth	Total length	Max. depth
Mm.	Mm.	E	R	E	R	E	R	E	R	E	R	E	R	Mm.	Mm.	Mm.	Mm.
155	15	5	0	8	0	1	1	0	1	1	0	0	0	70	19	70	18
179	17	3	1	8	1	4	1	0	1	1	0	1	0	73	22	70	20
206	21	3	1	5	3	2	0	0	1	1	0	0	0	80	25	80	24
232	23	4	1	4	4	0	0	0	1	1	0	0	0	88	27	91	26
243	26	0	1	2	1	2	0	1	0	0	2	0	0	90	29	90	30
243	27	1	0	1	0	3	0	5	2	1	0	0	0	97	31	93	30
273	28	0	0	2	0	2	0	2	1	0	1	0	1	96	31	104	33
278	30	1	2	0	0	0	0	0	0	2	0	0	2	101	34	109	35
290	33	0	1	2	0	2	2	2	0	0	1	0	0	104	36	117	37

permit the determination of variations in depths of body associated with given total lengths. Such information was essential since in the practical application of this study the only measurement of body dimensions that will be necessary for a population are those of total length. However, to estimate the total length of a forage fish that a bass of a given size can swallow required the determination of the following linear equations:

$$L_{forage} = a + bD_{forage}$$

or

$$\log L_{forage} = \log a + b \log D_{forage}$$

To solve these regression equations simply called for a reversal of the variables on the coordinates, thus the same sums of squares and cross products were used in the actual computations.

In this study three different sets of equations for estimating the total lengths of the five selected forage species that bass can swallow were determined (Tables 42, 43, and 44). Two sets of these equations were computed from actual values of measurements while the third set was computed from logarithmic values of measurements.

The following two equations:

$$M = a' + b'L_{bass}$$

and

$$L_{forage} = a'' + b''D$$

(where a' and b' denote estimators for bass and a" and b" denote estimators for the forage fish) were then equated as follows:

$$L_{forage} = a'' + b'' (a' + b'L_{bass})$$

Upon substituting the value for the total length of a bass and the

Table 42. Regression equations, computed from actual values of measurements, for determining the total length of various forage fishes a largemouth bass of a given total length can swallow. Forage fish equations computed for full range of their total length.

Largemouth bass:

Mouth width to total length relationships. (From Table 6)

Total length range Mm.	Estimating equations	s
Less 100	M = 1.88 + 0.0775 L	0.68
100-199	M = -0.98 + 0.1043 L	2.13
200-299	M = -7.03 + 0.1358 L	3.21
300-399	M = -2.84 + 0.1212 L	4.39
400-499	M = -19.99 + 0.1755 L	5.47
500-595	M = -50.77 + 0.2405 L	6.42

Forage fish:

Maximum depth of body to total length relationships.

Species	Estimating equations	s
Bluegills	L = 19.10 + 2.3925 D	11.75
Redears	L = 6.06 + 2.8917 D	7.38
Green sunfish	L = 11.70 + 2.6859 D	4.96
Golden shiners	L = 18.30 + 3.8876 D	7.19
Goldfish	L = 22.09 + 2.5992 D	10.29

Table 43. Regression equations, computed from actual values of measurements, for determining the total length of various forage fishes a largemouth bass of a given total length can swallow. Forage fish equations computed for 100 millimeter intervals of total length.

Largemouth bass:

Mouth width to total length relationships same as given in Table 40.

Forage fish:

Maximum depth of body to total length relationships.

Species	Interval Mm.	Estimating equation	s
Bluegills	Less 100	$L = 15.89 + 2.4661\ D$	9.72
	100-199	$L = 42.26 + 1.9821\ D$	10.67
	200 +	$L = 114.20 + 1.1919\ D$	4.02
Redears	Less 100	$L = 4.12 + 2.9838\ D$	3.98
	100-199	$L = 3.44 + 2.9344\ D$	7.98
	200 +	$L = 174.40 + 0.7290\ D$	3.60
Green sunfish	Less 100	$L = 8.54 + 2.8691\ D$	4.16
	100-199	$L = 33.00 + 2.1642\ D$	6.18
Golden shiners	Less 100	$L = 15.63 + 4.0117\ D$	5.12
	100-199	$L = 33.63 + 3.4532\ D$	6.27
	200 +	$L = 107.07 + 1.9394\ D$	2.91
Goldfish	Less 100	$L = 34.98 + 1.8363\ D$	8.56
	100-199	$L = 54.02 + 1.8532\ D$	5.78

Table 44. Regression equations, computed from logarithmic values of measurements, for determining the total length of various forage fishes a largemouth bass of a given total length can swallow. Forage fish equations computed for full range of their total length.

Largemouth bass:

Mouth width to total length relationships. (From Table 7)

Total length range Mm.	Estimating equations	s
Less 100	$\log M = -0.5222 + 0.7518 \log L$	.0453
100-199	$\log M = -0.8623 + 0.9303 \log L$	.0758
200-299	$\log M = -1.6031 + 1.2633 \log L$	.0523
300-399	$\log M = -0.8347 + 0.9553 \log L$	.0423
400-499	$\log M = -2.0435 + 1.4362 \log L$	.0451
500-595	$\log M = -3.0377 + 1.8057 \log L$	.0294

Forage fish:

Maximum depth of body to total length relationships.

Species	Estimating equations	s
Bluegills	$\log L = .7821 + 0.8046 \log D$	.0063
Redears	$\log L = .5722 + 0.9451 \log D$	.0073
Green sunfish	$\log L = .7179 + 0.8470 \log D$	.0124
Golden shiners	$\log L = .8981 + 0.8367 \log D$	.0176
Goldfish	$\log L = .9864 + 0.6815 \log D$	.0170

appropriate estimators for a', b', a", and b" the total length of a given species of forage fish the bass can swallow may be estimated.

The estimated total length of each forage species computed from equations given in Tables 42, 43, and 44, for each 0.5 inch total length interval (from 2 through 23 inches) of bass are given in Tables 45, 46, 47, 48, and 49. Graphic relationships between the total length of bass and estimated total length of bluegills, determined from equations in Tables 42 and 44 are shown in Figures 12 and 13.

Since the aquaria feeding tests showed that bass can swallow forage fishes whose maximum depth of body was greater than their mouth width (Tables 40 and 41), a comparison of the estimated with the actual total lengths of bluegills and goldfish fed these bass was made (Tables 50 and 51). Using the final measurements of the bass included in the aquaria feeding tests, the estimated total length of the bluegills and goldfish they could swallow were determined from equations based upon total length and from equations based upon mouth width of the bass (Table 42). Also included in these tables are the maximum total lengths of the fishes swallowed by each bass during the last month of the test. This period was selected since during this time each bass swallowed practically every fish that was offered.

The data given in Tables 50 and 51 indicate that the estimated total length of the five forage species that bass can swallow (Tables 45, 46, 47, 48, and 49) are probably conservative. However, it must be remembered that these are estimated total lengths of forage fishes and in their computation two error terms had to be combined, one for mouth width

Table 45. Estimated total length of bluegills which can be swallowed by largemouth bass of a given total length. Estimated total lengths were determined by equations given in Tables 42, 43, and 44.

Largemouth bass			Total length of bluegills which may be swallowed by bass as estimated by various equations					
Total length		M.W.	Actual values				Logarithmic values	
			Total range		100 millimeter range		Total range	
In.	Mm.	Mm.	In.	Mm.	In.	Mm.	In.	Mm.
2.0	51	5.8	1.30	33	1.14	29	0.98	25
.5		6.8	1.38	35	1.22	31	1.10	28
3.0	77	7.8	1.50	38	1.34	34	1.26	32
.5		8.8	1.57	40	1.42	36	1.38	35
4.0	102	9.7	1.65	42	1.54	39	1.54	39
.5		11.0	1.77	45	1.65	42	1.67	43
5.0	127	12.3	1.93	49	1.81	46	1.81	46
.5		13.6	2.05	52	1.93	49	1.93	49
6.0	152	14.9	2.17	55	2.05	52	2.08	53
.5		16.2	2.28	58	2.20	56	2.20	56
7.0	178	17.6	2.40	61	2.32	59	2.32	59
.5		18.9	2.52	64	2.48	63	2.44	62
8.0	203	20.5	2.68	68	2.64	67	2.72	69
.5		22.3	2.83	72	2.80	71	2.91	74
9.0	229	24.1	3.03	77	2.99	76	3.07	78
.5		25.8	3.19	81	3.19	81	3.24	82
10.0	254	27.5	3.35	85	3.35	85	3.40	86
.5		29.2	3.50	89	3.50	89	3.60	91
11.0	279	30.9	3.66	93	3.70	94	3.74	95
.5		32.6	3.82	97	3.86	98	3.94	100
12.0	305	34.1	3.97	101	4.33	110	4.13	105
.5		35.7	4.13	105	4.45	113	4.25	108
13.0	330	37.2	4.25	108	4.57	116	4.37	111
.5		38.7	4.41	112	4.68	119	4.52	115

7.0	178	17.6	2.40	61	2.32	59	2.32	59
.5		18.9	2.52	64	2.48	63	2.44	62
8.0	203	20.5	2.68	68	2.64	67	2.72	69
.5		22.3	2.83	72	2.80	71	2.91	74
9.0	229	24.1	3.03	77	2.99	76	3.07	78
.5		25.8	3.19	81	3.19	81	3.24	82
10.0	254	27.5	3.35	85	3.35	85	3.40	86
.5		29.2	3.50	89	3.50	89	3.60	91
11.0	279	30.9	3.66	93	3.70	94	3.74	95
.5		32.6	3.82	97	3.86	98	3.94	100
12.0	305	34.1	3.97	101	4.33	110	4.13	105
.5		35.7	4.13	105	4.45	113	4.25	108
13.0	330	37.2	4.25	108	4.57	116	4.37	111
.5		38.7	4.41	112	4.68	119	4.52	115
14.0	356	40.3	4.53	115	4.80	122	4.64	118
.5		41.9	4.69	119	4.92	125	4.80	122
15.0	381	43.3	4.84	123	5.03	128	4.88	124
.5		44.9	4.96	126	5.16	131	5.04	128
16.0	406	51.3	5.59	142	5.67	144	5.59	142
.5		53.5	5.79	147	5.83	148	5.83	148
17.0	432	55.8	6.02	153	6.02	153	6.02	153
.5		58.1	6.22	158	6.18	157	6.22	158
18.0	457	60.2	6.42	163	6.37	162	6.42	163
.5		62.5	6.65	169	6.54	166	6.65	169
19.0	483	64.8	6.85	174	6.73	171	6.85	173
.5		67.1	7.09	180	6.88	175	7.09	180
20.0	508	71.4	7.48	190	7.24	184	7.36	187
.5		74.5	7.76	197	7.48	190	7.64	194
21.0	533	77.4	8.03	204	7.72	196	7.91	201
.5		80.5	8.35	212	8.27	210	8.19	208
22.0	559	83.7	8.66	220	8.42	214	8.46	215
.5		86.8			8.58	218		
23.0	584	89.7						
.5		92.8						

Table 46. Estimated total length of redear sunfish which can be swallowed by largemouth bass of a given total length. Estimated total lengths were determined by equations given in Tables 42, 43, and 44.

Largemouth bass			Total length of redear sunfish which may be swallowed by bass as estimated by various equations					
Total length		M.W.	Actual values				Logarithmic values	
			Total range		100 millimeter range		Total range	
In.	Mm.	Mm.	In.	Mm.	In.	Mm.	In.	Mm.
2.0	51	5.8	0.91	23	0.87	22	0.79	20
.5		6.8	1.02	26	0.98	25	0.91	23
3.0	77	7.8	1.14	29	1.06	27	1.02	26
.5		8.8	1.26	32	1.18	30	1.14	29
4.0	102	9.7	1.34	34	1.30	33	1.30	33
.5		11.0	1.50	38	1.46	37	1.46	37
5.0	127	12.3	1.65	42	1.61	41	1.61	41
.5		13.6	1.77	45	1.77	45	1.73	44
6.0	152	14.9	1.93	49	1.93	49	1.85	47
.5		16.2	2.07	53	2.07	53	2.01	51
7.0	178	17.6	2.24	57	2.24	57	2.13	54
.5		18.9	2.40	61	2.40	61	2.28	58
8.0	203	20.5	2.56	65	2.56	65	2.56	65
.5		22.3	2.76	70	2.80	71	2.76	70
9.0	229	24.1	2.99	76	2.99	76	2.95	75
.5		25.8	3.19	81	3.19	81	3.15	80
10.0	254	27.5	3.39	86	3.39	86	3.35	85
.5		29.2	3.58	91	3.58	91	3.54	90
11.0	279	30.9	3.74	95	3.78	96	3.74	95
.5		32.6	3.94	100	3.97	101	3.94	100
12.0	305	34.1	4.13	105	4.09	104	4.17	106
.5		35.7	4.29	109	4.25	108	4.33	110

.5		18.9	2.40	61	2.40	61	2.28	58
8.0	203	20.5	2.56	65	2.56	65	2.56	65
.5		22.3	2.76	70	2.80	71	2.76	70
9.0	229	24.1	2.99	76	2.99	76	2.95	75
.5		25.8	3.19	81	3.19	81	3.15	80
10.0	254	27.5	3.39	86	3.39	86	3.35	85
.5		29.2	3.58	91	3.58	91	3.54	90
11.0	279	30.9	3.74	95	3.78	96	3.74	95
.5		32.6	3.94	100	3.97	101	3.94	100
12.0	305	34.1	4.13	105	4.09	104	4.17	106
.5		35.7	4.29	109	4.25	108	4.33	110
13.0	330	37.2	4.48	114	4.45	113	4.49	114
.5		38.7	4.64	118	4.61	117	4.65	118
14.0	356	40.3	4.84	123	4.80	122	4.80	122
.5		41.9	5.00	127	4.96	126	4.96	126
15.0	381	43.3	5.16	131	5.12	130	5.11	130
.5		44.9	5.35	136	5.31	135	5.27	134
16.0	406	51.3	6.06	154	6.06	154	5.98	152
.5		53.5	6.34	161	6.30	160	6.26	159
17.0	432	55.8	6.57	167	6.57	167	6.50	165
.5		58.1	6.85	174	6.85	174	6.77	172
18.0	457	60.2	7.09	180	7.09	180	7.00	178
.5		62.5	7.36	187	7.36	187	7.32	186
19.0	483	64.8	7.60	193	7.64	194	7.56	192
.5		67.1	7.87	200	7.87	200	7.87	200
20.0	508	71.4	8.35	212	8.89	226	8.19	208
.5		74.5	8.70	221			8.58	218
21.0	533	77.4					8.94	227
.5		80.5						
22.0	559	83.7						
.5		86.8						
23.0	584	89.7						
.5		92.8						

Table 47. Estimated total length of green sunfish which can be swallowed by largemouth bass of a given total length. Estimated total lengths were determined by equations given in Tables 42, 43, and 44.

Largemouth bass			Total length of green sunfish which may be swallowed by bass as estimated by various equations					
Total length		M.W.	Actual values				Logarithmic values	
			Total range		100 millimeter range		Total range	
In.	Mm.	Mm.	In.	Mm.	In.	Mm.	In.	Mm.
2.0	51	5.8	1.06	27	0.98	25	0.91	23
.5		6.8	1.18	30	1.10	28	1.06	27
3.0	77	7.8	1.30	33	1.22	31	1.18	30
.5		8.8	1.38	35	1.34	34	1.30	33
4.0	102	9.7	1.50	38	1.42	36	1.46	37
.5		11.0	1.61	41	1.57	40	1.61	41
5.0	127	12.3	1.77	45	1.73	44	1.73	44
.5		13.6	1.89	48	1.89	48	1.89	48
6.0	152	14.9	2.05	52	2.00	51	2.00	51
.5		16.2	2.17	55	2.17	55	2.17	55
7.0	178	17.6	2.32	59	2.32	59	2.28	58
.5		18.9	2.44	62	2.48	63	2.48	63
8.0	203	20.5	2.64	67	2.64	67	2.68	68
.5		22.3	2.83	72	2.87	73	2.87	73
9.0	229	24.1	2.99	76	3.07	78	3.03	77
.5		25.8	3.19	81	3.27	83	3.23	82
10.0	254	27.5	3.39	86	3.43	87	3.39	86
.5		29.2	3.54	90	3.62	92	3.58	91
11.0	279	30.9	3.74	95	3.82	97	3.82	97
.5		32.6	3.90	99	4.01	102	3.94	100
12.0	305	34.1	4.06	103	4.21	107	4.13	105
.5		[illegible]	[illegible]	[illegible]	[illegible]	110	4.29	109

.5		18.9	2.44	62	2.48	63	2.48	63
8.0	203	20.5	2.64	67	2.64	67	2.68	68
.5		22.3	2.83	72	2.87	73	2.87	73
9.0	229	24.1	2.99	76	3.07	78	3.03	77
.5		25.8	3.19	81	3.27	83	3.23	82
10.0	254	27.5	3.39	86	3.43	87	3.39	86
.5		29.2	3.54	90	3,62	92	3.58	91
11.0	279	30.9	3.74	95	3.82	97	3.82	97
.5		32.6	3.90	99	4.01	102	3.94	100
12.0	305	34.1	4.06	103	4.21	107	4.13	105
.5		35.7	4.25	108	4.33	110	4.29	109
13.0	330	37.2	4.41	112	4.48	114	4.41	112
.5		38.7	4.57	116	4.61	117	4.57	116
14.0	356	40.3	4.72	120	4.72	120	4.72	120
.5		41.9	4.88	124	4.88	124	4.84	123
15.0	381	43.3	5.04	128	5.00	127	4.96	126
.5		44.9	5.20	132	5.12	130	5.12	130
16.0	406	51.3	5.86	149	5.67	144	5.71	145
.5		53.5	6.10	155	5.86	149	5.98	152
17.0	432	55.8	6.38	162	6.06	154	6.14	156
.5		58.1	6.61	168	6.26	159	6.42	163
18.0	457	60.2	6.81	173	6.42	163	6.61	168
.5		62.5	7.09	180	6.61	168	6.85	174
19.0	483	64.8	7.32	186	6.81	173	7.05	179
.5		67.1			7.00	178	7.28	185
20.0	508	71.4			7.40	188		
.5		74.5						
21.0	533	77.4						
.5		80.5						
22.0	559	83.7						
.5		86.8						
23.0	584	89.7						
.5		92.8						

Table 48. Estimated total length of golden shiners which can be swallowed by largemouth bass of a given total length. Estimated total lengths were determined by equations given in Tables 42, 43, and 44.

Largemouth bass			Total length of golden shiners which may be swallowed by bass as estimated by various equations					
Total length		M.W.	Actual values				Logarithmic values	
			Total range		100 millimeter range		Total range	
In.	Mm.	Mm.	In.	Mm.	In.	Mm.	In.	Mm.
2.0	51	5.8	1.61	41	1.54	39	1.34	34
.5		6.8	1.77	45	1.69	43	1.54	39
3.0	77	7.8	1.93	49	1.85	47	1.73	44
.5		8.8	2.09	53	2.01	51	1.93	49
4.0	102	9.7	2.20	56	2.17	55	2.17	55
.5		11.0	2.40	61	2.36	60	2.36	60
5.0	127	12.3	2.60	66	2.56	65	2.56	65
.5		13.6	2.80	71	2.76	70	2.76	70
6.0	152	14.9	2.99	76	2.95	75	2.95	75
.5		16.2	3.19	81	3.19	81	3.15	80
7.0	178	17.6	3.43	87	3.39	86	3.35	85
.5		18.9	3.62	92	3.58	91	3.54	90
8.0	203	20.5	3.86	98	3.86	98	3.90	99
.5		22.3	4.12	105	4.37	111	4.17	106
9.0	229	24.1	4.41	112	4.61	117	4.45	113
.5		25.8	4.64	118	4.84	123	4.69	119
10.0	254	27.5	4.92	125	5.07	129	4.92	125
.5		29.2	5.16	131	5.28	134	5.12	133
11.0	279	30.9	5.43	138	5.51	140	5.47	139
.5		32.6	5.71	145	5.75	146	5.75	146
12.0	305	34.1	5.94	151	5.94	151	6.06	154

7.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
.5		18.9	3.62	92	3.58	91	3.54	90
8.0	203	20.5	3.86	98	3.86	98	3.90	99
.5		22.3	4.12	105	4.37	111	4.17	106
9.0	229	24.1	4.41	112	4.61	117	4.45	113
.5		25.8	4.64	118	4.84	123	4.69	119
10.0	254	27.5	4.92	125	5.07	129	4.92	125
.5		29.2	5.16	131	5.28	134	5.12	133
11.0	279	30.9	5.43	138	5.51	140	5.47	139
.5		32.6	5.71	145	5.75	146	5.75	146
12.0	305	34.1	5.94	151	5.94	151	6.06	154
.5		35.7	6.18	157	6.19	157	6.26	159
13.0	330	37.2	6.37	162	6.37	162	6.42	163
.5		38.7	6.61	168	6.57	167	6.65	169
14.0	356	40.3	6.85	174	6.81	173	6.81	173
.5		41.9	7.13	181	7.00	178	7.00	178
15.0	381	43.3	7.32	186	7.20	183	7.20	183
.5		44.9	7.55	192	7.44	189	7.40	188
16.0	406	51.3	8.54	217	8.15	207	8.26	210
.5		53.5			8.26	210	8.62	219
17.0	432	55.8			8.46	215		
.5		58.1						
18.0	457	60.2						
.5		62.5						
19.0	483	64.8						
.5		67.1						
20.0	508	71.4						
.5		74.5						
21.0	533	77.4						
.5		80.5						
22.0	559	83.7						
.5		86.8						
23.0	584	89.7						
.5		92.8						

Table 49. Estimated total length of goldfish which can be swallowed by largemouth bass of a given total length. Estimated total lengths were determined by equations given in Tables 42, 43, and 44.

Largemouth bass			Total length of goldfish which may be swallowed by bass as estimated by various equations					
Total length		M.W.	Actual values				Logarithmic values	
			Total range		100 millimeter range		Total range	
In.	Mm.	Mm.	In.	Mm.	In.	Mm.	In.	Mm.
2.0	51	5.8	1.46	37	1.81	46	1.26	32
.5		6.8	1.58	40	1.85	47	1.42	36
3.0	77	7.8	1.65	42	1.93	49	1.54	39
.5		8.8	1.77	45	2.01	51	1.69	43
4.0	102	9.7	1.85	47	2.07	53	1.85	47
.5		11.0	2.00	51	2.17	55	2.01	51
5.0	127	12.3	2.13	54	2.28	58	2.13	54
.5		13.6	2.24	57	2.36	60	2.24	57
6.0	152	14.9	2.40	61	2.44	62	2.40	61
.5		16.2	2.52	64	2.56	65	2.52	64
7.0	178	17.6	2.68	68	2.63	67	2.64	67
.5		18.9	2.80	71	2.76	70	2.76	70
8.0	203	20.5	2.95	75	2.87	73	2.99	76
.5		22.3	3.15	80	2.99	76	3.19	81
9.0	229	24.1	3.35	85	3.11	79	3.31	84
.5		25.8	3.50	89	3.23	82	3.46	88
10.0	254	27.5	3.70	94	3.35	85	3.62	92
.5		29.2	3.86	98	3.50	89	3.82	97
11.0	279	30.9	4.01	102	3.62	92	3.94	100
.5		32.6	4.21	107	3.74	95	4.09	104
12.0	305	34.1	4.37	111	3.86	98	4.25	108
.5		35.7	4.53	115	4.72	120	4.37	111
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

.5		18.9	2.80	71	2.76	70	2.76	70
8.0	203	20.5	2.95	75	2.87	73	2.99	76
.5		22.3	3.15	80	2.99	76	3.19	81
9.0	229	24.1	3.35	85	3.11	79	3.31	84
.5		25.8	3.50	89	3.23	82	3.46	88
10.0	254	27.5	3.70	94	3.35	85	3.62	92
.5		29.2	3.86	98	3.50	89	3.82	97
11.0	279	30.9	4.01	102	3.62	92	3.94	100
.5		32.6	4.21	107	3.74	95	4.09	104
12.0	305	34.1	4.37	111	3.86	98	4.25	108
.5		35.7	4.53	115	4.72	120	4.37	111
13.0	330	37.2	4.69	119	4.84	123	4.49	114
.5		38.7	4.84	123	4.96	126	4.61	117
14.0	356	40.3	5.00	127	5.07	129	4.72	120
.5		41.9	5.16	131	5.19	132	4.84	123
15.0	381	43.3					4.96	126
.5		44.9					5.12	130
16.0	406	51.3						
.5		53.5						
17.0	432	55.8						
.5		58.1						
18.0	457	60.2						
.5		62.5						
19.0	483	64.8						
.5		67.1						
20.0	508	71.4						
.5		74.5						
21.0	533	77.4						
.5		80.5						
22.0	559	83.7						
.5		86.8						
23.0	584	89.7						
.5		92.8						

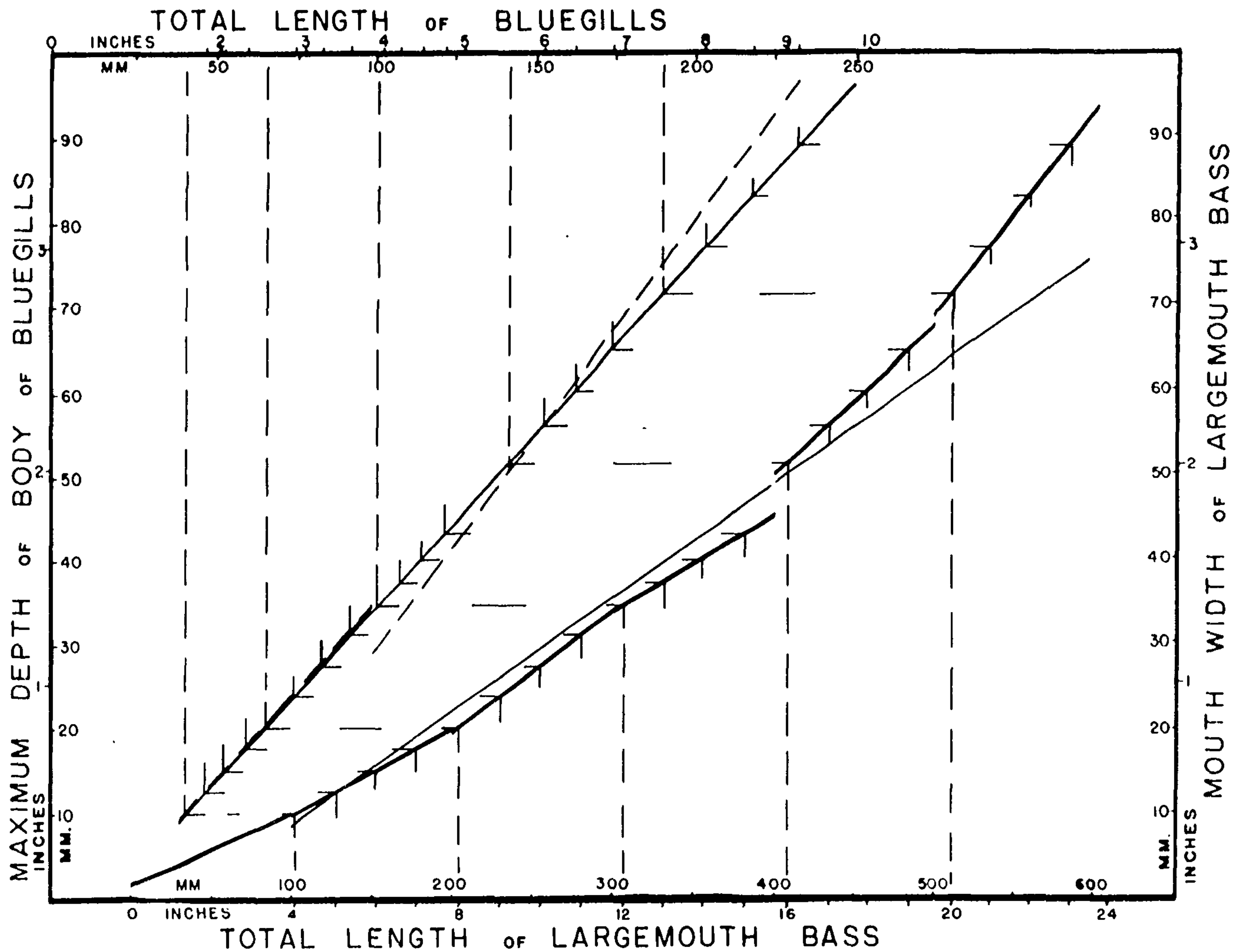

Figure 12. Estimated total lengths of bluegills that largemouth bass of given total lengths can swallow as determined from equations given in Table 42.

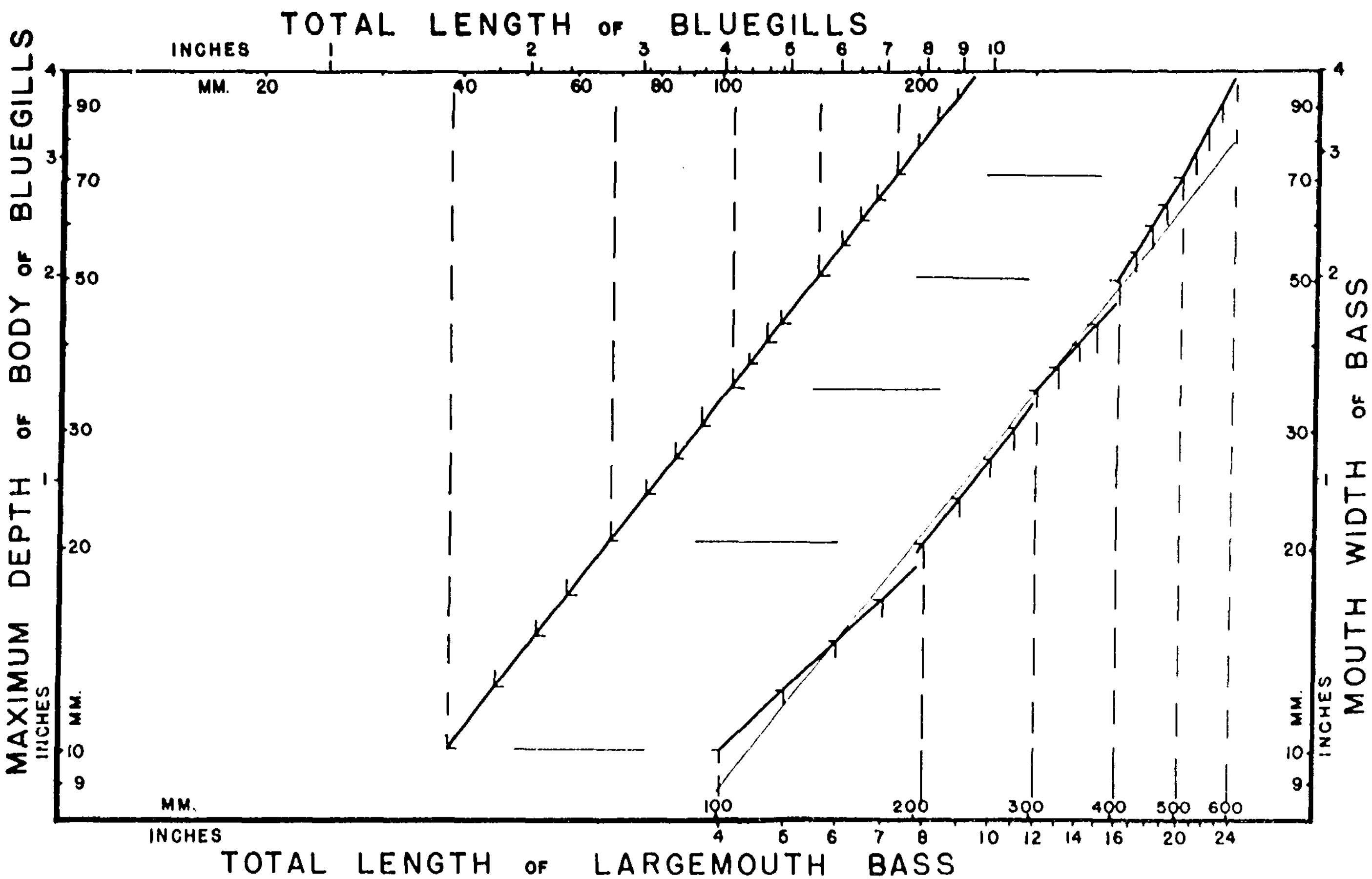

Figure 13. Estimated total lengths of bluegills that largemouth bass of given total lengths can swallow as determined from equations given in Table 44.

Table 50. Comparisons of estimated total lengths of bluegills with actual total lengths of bluegills largemouth bass in aquaria test swallowed (August 6 to September 6, 1954).

Largemouth bass			Bluegills		
Total length Mm.	Mouth width Actual Mm.	Mouth width Estimated Mm.	Maximum total length swallowed Mm.	Estimated * total length which can be swallowed Mm.	Estimated ** total length which can be swallowed Mm.
160	17.0	15.7	65	60	56
181	17.0	17.9	62	60	62
190	19.0	18.8	68	64	64
190	20.0	18.8	67	67	64
200	20.0	20.1	73	67	67
200	22.0	20.1	75	72	67
210	23.0	21.5	72	74	70
212	23.0	21.8	76	74	71
215	24.0	22.2	84	76	72
223	24.0	23.3	78	76	75
225	25.0	23.5	76	79	75
227	22.0	23.8	68	72	76
229	25.0	24.1	73	79	77
242	25.0	25.8	76	79	81
243	29.0	26.0	86	88	81
245	26.0	26.2	90	81	82
260	30.0	28.3	100	91	87
264	28.0	28.8	90	86	88
267	32.0	29.2	85	96	89
268	31.0	29.4	95	93	89
270	32.0	29.6	90	96	90
275	32.0	30.3	92	96	92
280	33.0	31.0	95	98	93
282	33.0	31.3	101	98	94
290	35.0	32.4	104	103	97

* Estimated total length determined from actual values of mouth width and using equations for bluegills given in Table 42.

** Estimated total length of bluegills determined from total length of bass using equations given in Table 42.

Table 51. Comparisons of estimated total lengths of goldfish with actual total lengths of goldfish largemouth bass in aquaria test swallowed.

Largemouth bass			Goldfish		
Total length Mm.	Actual Mm.	Estimated Mm.	Maximum total length swallowed Mm.	Estimated* total length which can be swallowed Mm.	Estimated ** total length which can be swallowed Mm.
160	17.0	15.7	70	66	63
181	17.0	17.9	85	66	69
190	19.0	18.8	80	72	71
190	20.0	18.8	75	74	71
200	20.0	20.1	82	74	74
200	22.0	20.1	82	79	74
210	23.0	21.5	87	82	78
212	23.0	21.8	95	82	79
215	24.0	22.2	90	84	80
223	24.0	23.3	96	84	83
225	25.0	23.5	86	87	83
227	22.0	23.8	82	79	84
229	25.0	24.1	95	87	85
242	25.0	25.8	100	87	89
243	29.0	26.0	100	97	90
245	26.0	26.2	95	90	90
260	30.0	28.3	110	100	96
264	28.0	28.8	100	95	97
267	32.0	29.2	106	105	98
268	31.0	29.4	106	103	98
270	32.0	29.6	105	105	99
275	32.0	30.3	100	105	101
280	33.0	31.0	110	108	103
282	33.0	31.3	107	108	103
290	35.0	32.4	110	113	106

* Estimated total length determined from actual values of mouth width and using equations for goldfish given in Table 42.

** Estimated total length of goldfish determined from total length of bass using equations given in Table 42.

determined from total length of bass, and one for total length determined from the maximum depth of body of the forage fishes. Thus, for individual forage fishes which were fed these bass, differences in actual and estimated total lengths are to be expected.

Certainly, for the present, the equations for estimating sizes of selected forage fishes largemouth bass of a given size can swallow offer the most reliable information on this subject that is available.

One factor which can affect the estimated total length of forage fish a largemouth bass can swallow was evident in the data in Tables 50 and 51. Some of the bass in the feeding tests had at one time or another some erosion of the caudal fin, thus their total length was less than for a normal bass. This led to differences in estimated total lengths of forage fishes as determined from total length equations and from mouth width equation for the bass. Such a condition might also occur in natural populations and thus give erroneous estimates. However, with careful observations afflicted individuals could be detected.

Application of Relationships of Mouth Width of Bass to Maximum Depth of Body of Forage Fish in Fisheries Management

The third phase of this study is concerned with demonstrating the application of the information derived in the two preceding sections to problems in fisheries management. According to the work of Swingle and Smith (1940) the largemouth bass is a necessary component of a pond population. The role of the bass, aside from its desirability for fishing, is to thin the small fish in a population, thus permitting those escaping to grow to an edible size. It has also been shown by these workers that the bluegill is the only species of forage fish which can reproduce in sufficient numbers to supply adequate food for the bass and yet perpetuate themselves in such abundance as to provide a desirable harvestable crop year after year.

The relationships between numbers and sizes of largemouth bass and forage fishes in pond populations were discussed at length by Swingle (1950). He gave numerical ratios, such as "E" values, "A_t", "F/C", and "Y/C", by which it could be determined if these ponds were supporting balanced populations of fish. Balanced populations are those in which the fish were capable of perpetuating themselves and producing a yearly crop of harvestable fish. It is to one of these ratios, namely the "Y/C", that the relationships of mouth width of bass to maximum depth of body of forage fishes, as determined by this study, are directly applicable.

In Swingle's paper the "Y" group included those forage fishes small enough to be eaten by the average size largemouth bass. The values he used were arbitrary ones and varied from population to population, since no method for establishing the exact size of forage fishes the bass could swallow were available. The relationships determined by the present study provide estimates for determining which groups of forage fishes should be included in the "Y" groups based upon the sizes of largemouth bass present in the population. Thus a more accurate "Y/C" ratio for a pond population, where bass are the principal or only "C" species, can now be determined.

The estimating equations for relationships between mouth width of bass and maximum depth of body of forage fishes can also be used to determine the poundage of "Y" species available as food for a given inch-group of largemouth bass. Several other techniques for determining similar breakdowns of the fish population in a pond or lake are readily evident. Two of these separations, believed to be most applicable, will be given in this discussion.

The first breakdown is computed in the same manner for each inch-group of bass as was employed by Swingle for his pond population "Y/C" ratio. This gives a series of cumulative "y/c" ratios for the largemouth bass inch-groups. The method employed to obtain these cumulative "y/c" ratios is illustrated using the population of fish recovered upon draining a 1.4 acre pond. The draining records (Table 52) gave the following population values: $E = 41.1$; $F/C = 11.3$; $Y/C = 5.7$; $A_t = 40.4$; $A_f = 37.2$. These values indicated, according to Swingle's analyses, that this pond was overcrowded with small forage fish.

The relationships between mouth width of bass and maximum depth of body of bluegills, as given in Table 45, were then applied to these population data to determine the cumulative poundages of bluegills available to each inch group of bass. As an example, for the 6 inch-group of bass the minimum total length of bluegills is 52 millimeters (2.05 inches) and the maximum is 58 millimeters (2.28 inches). Assuming a uniform distribution by weight of the bluegills in the 2 inch-group, this represents 23 percent of the total weight of that inch-group ($2.28 - 2.05 = .23$) as the available food supply for bass in the 6 inch group. These 6 inch-group bass then had 3.08 pounds of bluegills ($13.40 \times .23 = 3.08$) as their food supply. However, these bass could also swallow all

Table 52. The numbers and weights of various species of fish recovered upon draining of a 1.4 acre pond on October 23, 1952.

Inch group	Bluegills No.	Bluegills Pounds	Bass No.	Bass Pounds	Green sunfish No.	Green sunfish Pounds	Round fliers No.	Round fliers Pounds
1	1641	1.15						
2	2795	13.40						
3	6239	113.54	194	3.21				
4	3940	149.00	268	6.43				
5	557	44.53	36	1.41	8	0.88	9	1.24
6	215	27.13	20	1.51			4	0.65
7	287	57.05	4	0.51			40	12.01
8	11	3.31	3	0.53			210	87.81
9							11	5.25
10								
11			1	0.78				
12								
13			3	3.56				
14			15	18.68				
15			8	12.09				
Total		407.11	552	48.71		0.88		106.96

Total pond production - 563.66 pounds

Pounds per acre 402.61

"E" = 41.1 A_t = 40.4

"F/C" = 11.3 A_f = 37.2

"Y/C" = 5.7

bluegills smaller than 2.05 inches total length, thus there were 55 percent additional 2 inch-group bluegills (13.40 x .55 = 7.37) and all of the 1 inch-group (1.15 pounds) bluegills available. Thus their accumulated supply of bluegills was 1.15 + 7.37 + 3.08 = 11.60 pounds. There were also some 3 inch group (3.21 pounds), some 4 inch-group (6.43 pounds) and some 5 inch-group (1.41 pounds) largemouth bass present in this population and they were drawing upon these smaller bluegills (less than 2.05 inches total length) for their food. Thus in computing the cumulative "y/c" ratio for the 6 inch-group of bass the accumulated weight of bluegills available as food was divided by the accumulated weight of bass, that is "y" = 11.60 pounds, and "c" = 12.56 pounds, then "y/c" = 11.60/12.56 = 0.92. The detailed breakdown of the weights of bluegills to obtain these cumulated "y/c" ratios for each inch-group of bass are given in Table 53.

A second, or proportional, method used numbers of bass and weights of bluegills to determine the "y/c" ratios for each inch-group of bass. Using this method the weight of bluegills available as food for a given inch-group of bass was determined from the value given in Table 45. This weight of bluegills was then proportionally distributed over the entire size groups of bass, which could swallow these bluegills, based upon the numbers of bass present in each inch-group. As an example, for the 3 inch-group of bass the percentage of numbers of bass in all inch-groups was determined as shown in Table 54. The weight of bluegills, which was 2.09 pounds (1.15 pounds of 1 inch-group plus 13.40 x .07 = 0.94 pounds of 2 inch-group), was then proportioned according to these percentages of numbers over the ten inch-groups of bass present in the population.

Table 53. Accumulated weights of bluegills available as food for each inch-group of bass for fish population from 1.4 acre pond.

Bass inch group	Bass cum. pounds	Weights of bluegills by inch-groups 1 lb.	2 lbs.	3 lbs.	4 lbs.	5 lbs.	Total "y" pounds
3	3.21	1.15	0.94				2.09
4	9.64	1.15	3.62				4.77
5	11.05	1.15	7.37				8.52
6	12.56	1.15	10.45				11.60
7	13.07	1.15	13.40	2.27			16.82
8	13.60	1.15	13.40	37.47			52.02
11	14.38	1.15	13.40	113.54	47.68		175.77
13	17.94	1.15	13.40	113.54	135.59		263.68
14	36.62	1.15	13.40	113.54	149.00	8.46	285.55
15	48.71	1.15	13.40	113.54	149.00	20.48	297.57

Then for the 4 inch-group of bass the percentages of numbers present in the nine remaining inch-groups had to be computed. These percentages are also shown in Table 54. The weight of bluegills, not previously obligated to the 3 inch-group bass, available to the 4 inch-group of bass was 2.68 pounds (13.40 x .20 = 2.68). This weight of bluegills was then proportioned over the nine remaining inch-groups of bass based upon the percentage of numbers as shown in Table 54. The same procedure as given above for the 4 inch-group of bass was followed for the 5 and 6 inch-groups. However, for the 7 inch-group of bass the weight of bluegills included the remainder of the 2 inch-group not already obligated by the 6 inch-group of bass

Table 54. Percentage distribution, by inch-groups, of bass which can swallow bluegills of various sizes*, for fish population from 1.4 acre pond.

Largemouth bass Inch-group	No.	Under 1.57	1.58-1.77	1.78-2.05	2.05-2.28	2.29-2.52	2.53-2.83	2.84-3.82	3.83-4.41	4.42-4.69	4.70-4.96
		Percentages of bass in each inch-group which can swallow bluegills in each size group									
3	194	35.14									
4	268	48.55	74.86								
5	36	6.52	10.05	40.00							
6	20	3.62	5.59	22.22	37.03						
7	4	0.72	1.11	4.44	7.41	11.76					
8	3	0.54	0.84	3.33	5.56	8.82	10.00				
11	1	0.18	0.28	1.11	1.85	2.94	3.33	3.70			
13	3	0.54	0.84	3.33	5.56	8.82	10.00	11.11	11.54		
14	15	2.72	4.19	16.67	27.78	44.12	50.00	55.56	57.69	65.21	
15	8	1.45	2.23	8.88	14.81	23.52	26.67	29.63	30.77	34.79	100.00
Number of bass preying on this size group		552	358	90	54	34	30	27	26	23	8

* Size group of bluegills selected on the basis of the lengths which can be swallowed by bass in consecutive inch-groups.

(1.00 - .78 = .22) plus the portion of 3 inch-group bluegills they could swallow (.02 - .00 = .02). The total weight of these bluegills amounted to 2.95 pounds of 2 inch-group (13.40 x .22 = 2.95) plus 2.27 pounds of 3 inch-group bluegills (113.54 x .02 = 2.27) to give a total of 5.22 pounds available as food for the 7 inch-group bass. This weight of bluegills was then proportioned over the six remaining inch-groups of bass according to the percent of numbers present in each group. The proportional breakdown of these bluegill weights for each inch-group of bass are given in Table 55.

To obtain the proportional "y/c" ratio for each inch-group of bass, the total weight of bluegills proportioned to each of the individual inch-groups of bass had to be determined. This total weight of bluegills, "y", was then divided by the weight of bass, "c", for that given inch-group.

The cumulative and proportional "y/c" ratios for this 1.4 acre pond were as follows:

Bass inch-groups	Cumulative "y/c"	Proportional "y/c"
3	0.65	0.229
4	0.49	0.470
5	0.77	1.351
6	0.92	1.457
7	1.29	2.067
8	3.83	8.132
11	12.22	7.717
13	14.70	7.922
14	7.80	8.313
15	6.11	7.845

Table 55. Weights of bluegills available as food for each inch-group of bass proportionally divided on the basis of numbers of bass present in each inch-group, for fish population from 1.4 acre pond.

Largemouth bass Inch-group	Largemouth bass weight pounds	Total length in inches of bluegills: Under 1.57	1.57-1.77	1.78-2.05	2.05-2.28	2.29-2.52	2.53-2.83	2.84-3.82	3.83-4.41	4.42-4.69	4.70-4.96	Sum "Y"
		Weight in pounds of bluegills by size groups										
3	3.21	.734										.734
4	6.43	1.014	2.006									3.020
5	1.41	.136	.269	1.500								1.905
6	1.51	.076	.150	.833	1.141							2.200
7	0.51	.015	.030	.167	.228	.614						1.054
8	0.53	.011	.023	.125	.171	.460	3.520					4.310
11	0.78	.004	.008	.042	.060	.154	1.172	4.579				6.019
13	3.56	.011	.023	.125	.171	.460	3.520	13.748	10.145			28.203
14	18.68	.057	.112	.625	.856	2.304	17.600	68.755	50.715	14.262		155.286
15	12.09	.031	.060	.333	.456	1.228	9.388	36.668	27.050	7.608	12.020	94.842
Total		2.09	2.68	3.75	3.08	5.22	35.20	123.75	87.91	21.87	12.02	297.57

An examination of these inch-group "y/c" ratios indicates that the 3, 4, 5, and 6 inch-groups of bass had a deficient food supply with no possibility of any replacement before the following spring, a period of approximately 6 months. The competition for this food during this 6 month period would have been so great that all four of these smaller inch-groups of bass would have suffered.

An examination of the "y/c" ratios for the larger inch-groups of bass indicates an abundance of food. In fact it is doubtful that the bass could have reduced the numbers of 3 and 4 inch-groups of bluegills sufficiently to allow those remaining to grow to a catchable size by the following summer. Had such a condition developed in this pond, it would have been severely overcrowded with bluegills. Consequently the bluegills would have spawned little or none in the spring, and as a result the small bass would have had to compete with the bluegills for bottom organisms to exist.

Thus are illustrated from the data of this 1.4 acre pond some of the inferences which may be drawn regarding a fish population using the relationships between mouth width of bass and maximum depth of body of forage fishes. When sufficient detailed draining records are available on ponds some very interesting and important characteristics of fish populations may be determined. No doubt as these breakdowns of the populations are analyzed, further applications of the relationships between mouth width of bass and maximum depth of body of forage fishes will be found.

SUMMARY

The purpose of this research was to determine the size of various forage fishes a largemouth bass, Micropterus salmoides Lac., of a given size can swallow and to derive prediction equations for estimating these size relationships. The relationship between mouth width and total length of largemouth bass was determined from 1377 individuals ranging in size from 31 to 595 millimeters total length. The mouth width measurements were made externally between the posterior margins of the preopercula with the opercular flaps in the closed position. There was no single linear equation determined from either actual or logarithmic values of measurements which would give satisfactory estimates of mouth widths over the entire range of total lengths. Rather, linear equations which covered only 100 millimeter intervals of total length had to be used to give satisfactory estimates of mouth widths. Equally accurate estimates of mouth widths, determined for 100 millimeter intervals of total lengths, were obtained from either actual or logarithmic values of measurements.

The total length ranges of forage fishes for which the relationships between maximum depth of body and total length were determined included the following: bluegill, Lepomis macrochirus Raf., 14-235 millimeters; redear sunfish, Lepomis microlophus Gunther, 75-220 millimeters; green sunfish, Lepomis cyanellus Raf., 14-181 millimeters; golden shiner, Notemigonus crysoleucas (Mitchill), 48-215 millimeters; and goldfish, Carassius auratus (Lin.), 35-130 millimeters. Single linear regression

equations, covering the full range of total lengths, were calculated for each of these species of forage fish. Equal accuracy of prediction was obtained using either actual or logarithmic values of measurements.

Dissection suggested that the width between the cleithrum bones limits the size of fish a bass can swallow. This width between the cleithrum bones was found to be the same as the mouth width measurement previously described. It was postulated that a largemouth bass of a given total length could swallow a forage fish whose maximum depth of body was equal to the mouth width of the bass. However feeding experiments indicated that bass would eat forage fish with maximum depths somewhat greater than the mouth width.

The estimated total lengths of the various forage fishes that largemouth bass of given total lengths can swallow were computed and tabulated. The equations used for estimating the mouth widths of largemouth bass were as follows:

total length		
less than 100 mm.	$M = 1.88 + 0.0775\ L$	$s = 0.68$
100 - 199 mm.	$M = -0.98 + 0.1043\ L$	$s = 2.13$
200 - 299 mm.	$M = -7.03 + 0.1358\ L$	$s = 3.21$
300 - 399 mm.	$M = -2.84 + 0.1212\ L$	$s = 4.39$
400 - 499 mm.	$M = -19.99 + 0.1755\ L$	$s = 5.47$
500 - 595 mm.	$M = -50.77 + 0.2405\ L$	$s = 6.42$

The equations for estimating the total lengths of forage fishes from maximum depth of body were as follows:

bluegills	$L = 19.10 + 2.3925D$	$s = 11.75$
redear sunfish	$L = 6.06 + 2.8917D$	$s = 7.38$

green sunfish	$L = 11.70 + 2.6859\ D$	$s = 4.96$
golden shiner	$L = 18.30 + 3.8876\ D$	$s = 7.19$
goldfish	$L = 22.09 + 2.5992\ D$	$s = 10.29$

The practical application of the relationships between mouth widths of bass and maximum depths of body of forage fishes was demonstrated using the fish population data obtained upon draining a 1.4 acre pond. It was shown that a more accurate Y/C ratio for a pond population, where the bass is the principal or only piscivorous species present, was possible since the actual size of forage fish available as food for the bass could be determined. It was also shown that cumulative and proportional y/c ratios for each inch-group of bass could be calculated. It was suggested that such calculated y/c ratios might aid considerably in determining the relationships within a fish population, particularly as concerns the "balance" within the population. It was also proposed that further applications of this relationship will be found when sufficiently detailed data, obtained from numerous populations of fish, are available for study.

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